Impacts of Climate Change on the Yangtze Source Region and Adjacent Areas

Qinghai-Tibet Plateau, China

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Location of the Yangtze Source Region, Qinghai-Tibet Plateau, China
(Map courtesy of Yongping Shen.)

Preface

The Qinghai-Tibet Plateau is the highest plateau on earth and is often referred to as “The Roof of the World.” Because of the extremely cold dry climate, soils on the plateau are not well developed, vegetation grows slowly, and the plateau’s ecosystems are extremely fragile. The source of the Yangtze River lies at an elevation of 5480 m in the heart of the Qinghai-Tibet Plateau, where the river originates from glacial meltwater and is later nourished by vast areas of alpine wetlands. This region is also the heartland of the Tibetan people’s unique nomadic herding culture.

However, since the 1980s, with western China’s rapid economic development and population growth, the fragile alpine grassland ecosystems of the Yangtze Source Region have been under increasing pressure brought about by human activities. The overstocking of grasslands with livestock, over-collection of endemic herbs, and unregulated exploitation of mineral resources have resulted in grassland degradation, pika and insect plagues, chronic soil erosion, and other environmental problems.

To add to these problems, global warming now poses another major threat to the Yangtze Source Region. Meteorological records show that temperatures in the Yangtze Source Region rose rapidly in the last two decades of the 20th Century and continue to rise today. As a result of this warming, accelerated meltoff of glaciers is adversely impacting the hydrology of rivers fed by glacial meltwater in the Yangtze Source Region. At the same time, groundwater levels have fallen in many parts of the region due to the degradation of permafrost caused by global warming, which now threatens vast areas of grasslands where grassroots no longer reach the groundwater table. In addition, warming itself may pose a direct threat to various species adapted to a cool alpine climate, while an increase in the number of extreme weather events resulting from climatic change, such as heavy rain and snowstorms, also threatens plateau ecosystems.

Given the multitude of environmental threats resulting from climate change and destructive human activities, both the plateau’s ecosystems and indigenous herding culture face uncertain futures, and their survival is by no means assured. Therefore it is imperative that an effective program of wetland conservation be carried out in the Yangtze Source Region to ensure the long-term viability of the region’s ecosystems and socioeconomic development. In recent years, the growing ecological problems of the Yangtze Source Region have drawn widespread attention throughout China, and a group of scientists has proposed a “Climate Adaptation and Sustainable Development Strategy” for the region which has received the backing of local officials and China’s central government.

Recognizing that an in-depth scientific understanding of the impacts of climate change on the Yangtze Source Region will serve as the basis for developing future conservation and development strategies for the region, in 2004 WWF-China initiated a project entitled "Wetland Conservation and Climate Change in the Yangtze Source Region." Under this project, funding was provided to conduct scientific research on the impacts of climate change on weather, wetland ecosystems, glaciers, permafrost, and livestock herding in the Yangtze Source Region. This research included original field work and data analysis as well as a comprehensive review of relevant scientific literature, the results of which are presented in the five chapters that follow.

Originally published in Chinese, this new English edition of the report has been thoroughly revised and updated where possible. New features of this edition of the report include full referencing of all source materials, expanded sections on the ecology of the northeastern Qinghai-Tibet Plateau, particularly with respect to Qinghai Lake and the Zoige Wetlands, as well as a greatly expanded analysis of the findings of the social survey presented in Chapter 5. Other new features of this edition of the report include new report-specific photos and an expanded glossary of technical terms as well as an appendix listing the locations and Romanized and Chinese character spellings of all geographic place names mentioned in the text. Finally appendices have been added that list the names and locations of all meteorological stations on the plateau, list all plant and animal species mentioned in the text, and present additional information on the glaciers of the upper Yangtze River watershed.

WWF hopes that the publication of this report will draw more attention to the numerous pressing environmental problems facing the Yangtze Source Region today, and it is also hoped that this report will spur further action towards developing and implementing effective climate change adaptation and wetland conservation strategies for the Yangtze Source Region. Only through the development of such climate adaptation and conservation strategies for the Yangtze headwaters will it be possible to achieve truly sustainable socioeconomic development of the entire Yangtze River basin.

Editor, Editorial Review Committee, and Authors
Lhasa and Beijing, October 2009

List of Acronyms Used

A.D.	*Anno Domini*
B.C.	Before Christ
CASS	Chinese Academy of Social Sciences
DEM	Digital Elevation Model
GIS	Geographic Information Systems
LIA	Little Ice Age
MWP	Medieval Warm Period
TAR	Tibet Autonomous Region
ybp	Years Before Present
YSR	Yangtze Source Region

Contents

1

Climate Change on the Qinghai-Tibet Plateau

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"We are facing challenges of a changing earth."
— Berrien Moore III, Executive Director of Climate Central (Moore 2002)

1.1 Introduction

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: 1) over the previous century (1906-2005), the global mean surface air temperature increased 0.74 ± 0.18ºC; 2) over the last 50 years, the planet has warmed at an average rate of 0.13 ± 0.03ºC/decade, which is nearly twice the rate of planetary warming for the previous century as a whole; 3) it is very likely that increases in anthropogenic greenhouse gases have caused most of the observed increase in global average temperatures since the mid-20th Century; and 4) unless greenhouse gas emissions are greatly reduced, global surface air temperatures at the end of the 21st Century are projected to be 1.1 to 6.4ºC higher than for the period from 1980-1999 (IPCC AR4 2007).

With an average altitude of over 4000 m above sea level and imposing topographic features, the Qinghai-Tibet Plateau plays an important role in influencing the global climate. Over the past 20 million years, the rapid uplift of the Qinghai-Tibet Plateau has changed the pattern of general atmospheric circulation in East Asia through both dynamic and thermodynamic processes. Furthermore, a plateau monsoon was established, while both the South and East Asian monsoons were intensified, which has increased precipitation in South and East Asia but has left the plateau itself colder and dryer (Zheng, Lin, and Zhang 2002). Due to the unique geography and environment of the plateau, including its extreme climate,

extensive wetlands, and fragile high altitude ecosystems, the Qinghai-Tibet Plateau is much more acutely affected by climate change than more resilient low-altitude regions. Thus, some observers are of the opinion that the Qinghai-Tibet Plateau is particularly sensitive to climate change and that the plateau itself may be the trigger of global warming (e.g. see Feng, Tang, and Wang 1998).

Impacts of global climate change on the plateau and its high altitude wetlands are diverse and include the meltoff of glaciers; melting of permafrost; changing temperature, precipitation, and evaporation patterns; alteration of grassland ecosystems; disappearance of wetlands, lakes, and rivers; and desertification, all of which can severely impact both ecosystems and human livelihoods on the plateau (e.g. see Shen 2004; Wang, Li, Wu, and Wang 2006; Lin, Zhang, and Yin 2000; Wilkes 2008; Li, Xu, Sun, Zhang, and Yang 2007; Zhang, Wu, Lu, Zhao, and Chen 2003). While wetlands are some of the most productive ecosystems on earth and have a large capacity for carbon fixation, they also release dissolved and particulate organic carbon to adjacent aquatic environments (Sahagian and Melack 1998). Consequently, wetlands play an important role in the biogeochemical carbon cycle, which itself influences the rate of global climate change. However, in many developing areas like Qinghai Province and the Tibet Autonomous Region (TAR), development needs and increasing populations combined with climate change impacts are accelerating the rate at which natural wetlands vanish. Therefore, better scientific understanding of climate change, local wetland characteristics, and their interdependence is necessary to efficiently and sustainably utilize wetlands on the Qinghai-Tibet Plateau, and to establish priorities for conservation of high altitude wetlands throughout the region.

1.2 Historical Climate Change on the Qinghai-Tibet Plateau over the Past 2000 Years

The study of historical climatic and environmental changes over the past 2000 years is important to understanding climate change at a regional and even a global scale. It is not only the period impacted most severely by human agricultural and industrial activities, but is also the period for which we have scientific as well as natural climate records, such as ice cores, tree rings, lake sediments, and pollen. During this period, two prominent climatic events took place, the Medieval Warm Period (MWP, roughly 800-1300 A.D.) and the Little Ice Age (LIA, roughly 1500-1850 A.D.).

Since the 1980s, the Chinese Academy of Sciences has conducted extensive research involving collection and study of ice cores and tree rings, from which several plateau climate sequences were reconstructed. As indicators of paleoclimates, both ice cores and tree rings are high-resolution climate records (e.g. see Yao, Xie, and Wu 1991; Esper, Cook, and Schweingruber 2002). Ice sheets and ice caps serve as libraries of atmospheric history, with the levels of $\delta^{18}O$ oxygen isotopes found in

ice cores being a direct indicator of the temperature at the time the ice was formed. A one part per thousand increase (or decrease) in $\delta^{18}O$ levels in precipitation indicates an increase (or decrease) in temperature of about 1.6ºC, while glacier net accumulation values reflect the variations in annual precipitation (Yao, Thompson, Qin, Tian, Jiao, Yang, and Xie 1996). As for tree-ring records, due to their ease of calibration, continuity, and widespread distribution, they are used extensively for millennial scale climate reconstruction, since both tree-ring width and density are good indicators of changing climatic conditions.

1.2.1 Historical Temperature Records for the Southern Tibet Autonomous Region

Wu and Lin reconstructed annual mean temperature sequences for the Lhasa area over the past 2000 years using tree-ring records (Wu and Lin 1981). Figure 1.1 indicates that at the beginning of the first millennium A.D. it was relatively cold, while a warm period began in the 6th Century. However, due to the scarcity of tree-ring data from the region for the period from the 7th to 12th Century, the MWP is poorly documented on the plateau, although supplemental historical documents suggest that the period was relatively warm. After this warm period, the Qinghai-Tibet Plateau entered the LIA and the climate grew cold again, especially in the mid-17th Century. During this period, although there were short episodes of warming, most evidence reflects an unusually cold climate on the plateau with nearly all mountain glaciers advancing simultaneously. In the mid-19th Century, the LIA ended and was followed by a modern warming period which began after the industrial revolution.

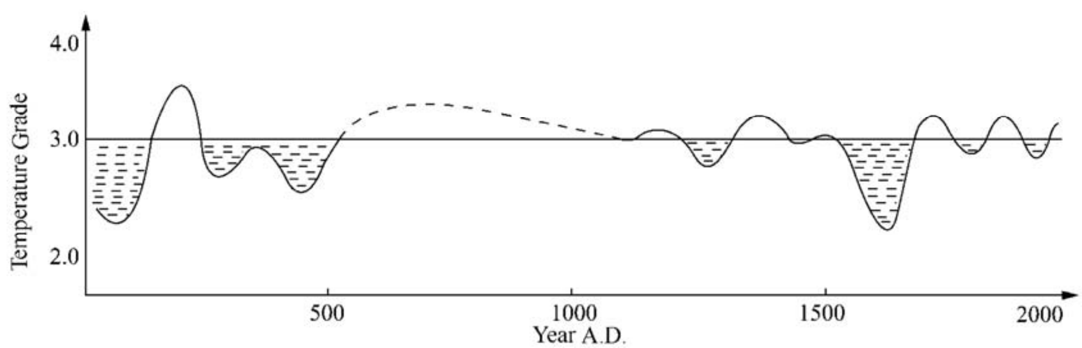

Figure 1.1. Temperature in the Lhasa Region over the past 2000 years reconstructed from tree-ring data and historical records.
Note: The solid line is reconstructed from tree-ring data, while the dashed line has been inferred from historical records. A 50 year moving-average has been applied to the original series, with three temperature grades set as follows: 3.0: normal temperature, greater than 3.0: warmer, less than 3.0: colder.
Source: Wu and Lin 1981.

1.2.2 History of Drought and Flooding on the Qinghai-Tibet Plateau

Photo 1.1. Aerial view of the Yarlung Tsangpo River, Lhoka Prefecture, TAR. Photo by Dawa Tsering.

Both the timing and duration of periods of flooding are important environmental indicators of the ecological history of wetlands. Reconstruction of the modern drought and flood history on the Qinghai-Tibet Plateau indicates that there were three rainy periods during the past 125 years (1883-1906, 1916-1934, and 1947-1962), as well as three dry periods (1907-1915, 1935-1946, and 1963-1980) (Fig. 1.2) (Lin, Zhang, and Yin 2000). Over this 125-year period, the number of dry days far exceeded the number of rainy days, with the first dry period lasting nine years, the second twelve years, and the third eighteen years, which suggests a trend of increasing aridity on the plateau. Climatic changes on the plateau have also been marked by other natural phenomenon, such as the lowering of groundwater levels, which is indicative of increasing aridity in the region (Lin, Zhang, and Yin 2000). In addition, many scientists believe that that there were other severely arid periods on the plateau in late 15th, late 17th, and early 18th Centuries as well (e.g. see Lin, Zhang, and Yin 2000; Yao, Xie, and Wu 1991).

According to climate reconstructions based on historical documents, the temporal and areal distribution of floods on the plateau from 1803 to 1958 showed consider-

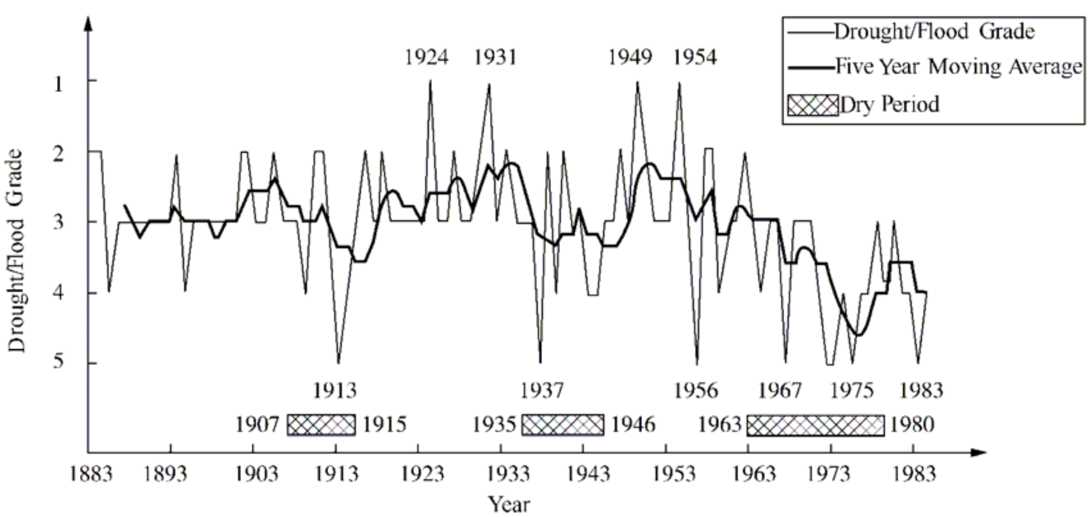

Figure 1.2. Reconstructed plateau drought/flood variation from 1883 to 1984.
Note: Drought and flood grades were set as follows: 1: severe flood, 2: moderate flood, 3: normal conditions, 4: moderate drought, 5: severe drought.
Source: Lin, Zhang, and Yin 2000.

able variation. Frequent, intense, precipitation-driven flooding occurred from the 1840s to 1880s and further severe flooding occurred from 1924 to 1954, with most flooding on the plateau being restricted to the Yarlung Tsangpo-Lhasa-Nyang River basins (Photos 1.1 and 1.2). During this period, flooding occurred most frequently in Shigatse and Lhoka Prefectures as well as in Lhasa Municipality and Nyingchi Prefecture, while little flooding occurred in Chamdo, Ngari, and Nagchu Prefectures (Zhang, Ge, and Lin 2001).

Photo 1.2. The Lhasa (Kyi Chu) River as it flows past downtown Lhasa, TAR. Photo by John D. Farrington.

1.2.3 Comparison of Guliya Ice-core and Dulan Tree-ring Records

Research shows that ice cores from the Guliya Ice Cap in the northwest TAR and tree-ring records from Dulan County in central Qinghai both provide good records of historical temperatures at their respective collection sites (Fig. 1.3, Photo 1.3) (Yao, Thompson, Qin, Tian, Jiao, Yang, and Xie 1996; Kang 2000; Zhang, Cheng, Yao, Kang, and Huang 2003). Comparison of these two high-resolution records shows that temperatures have increased in a fluctuating manner over the last 2000 years, particularly since the beginning of the 20th Century (Fig. 1.3) (Yao, Yang, and Kang 2001). Both records show three distinct cold periods occurring during the Little Ice Age and indicate that the LIA was not the coldest period of the last 2000 years, with, in all probability, the early centuries of the first millennium A.D. having been even colder. However, these ice-core and tree-ring records also have noticeable differences, such as the Dulan tree-ring series showing strong warming during the Medieval Warm Period, while the $\delta^{18}O$ series of the Guliya ice cores reflect this warm period much more weakly. After the MWP, temperatures indicated by the Dulan tree rings decreased in a fluctuating manner until about 1800, while during the same period a significant warming trend is revealed in the Guliya ice cores. Climate differences between proxy sample sites, proxy calibration errors, and impacts of other environmental factors on the reconstructed series are all possible causes of variations between the two series.

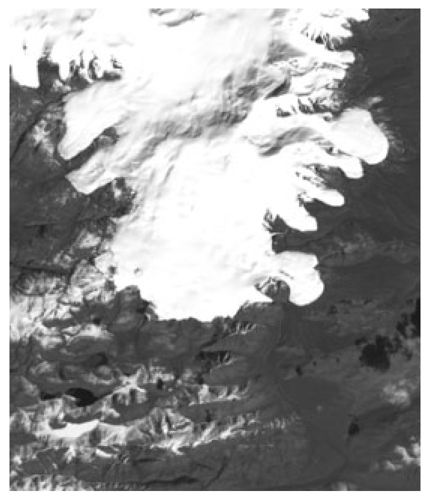

Photo 1.3. Guliya Ice Cap, Ngari Prefecture, TAR. NASA Landsat image.

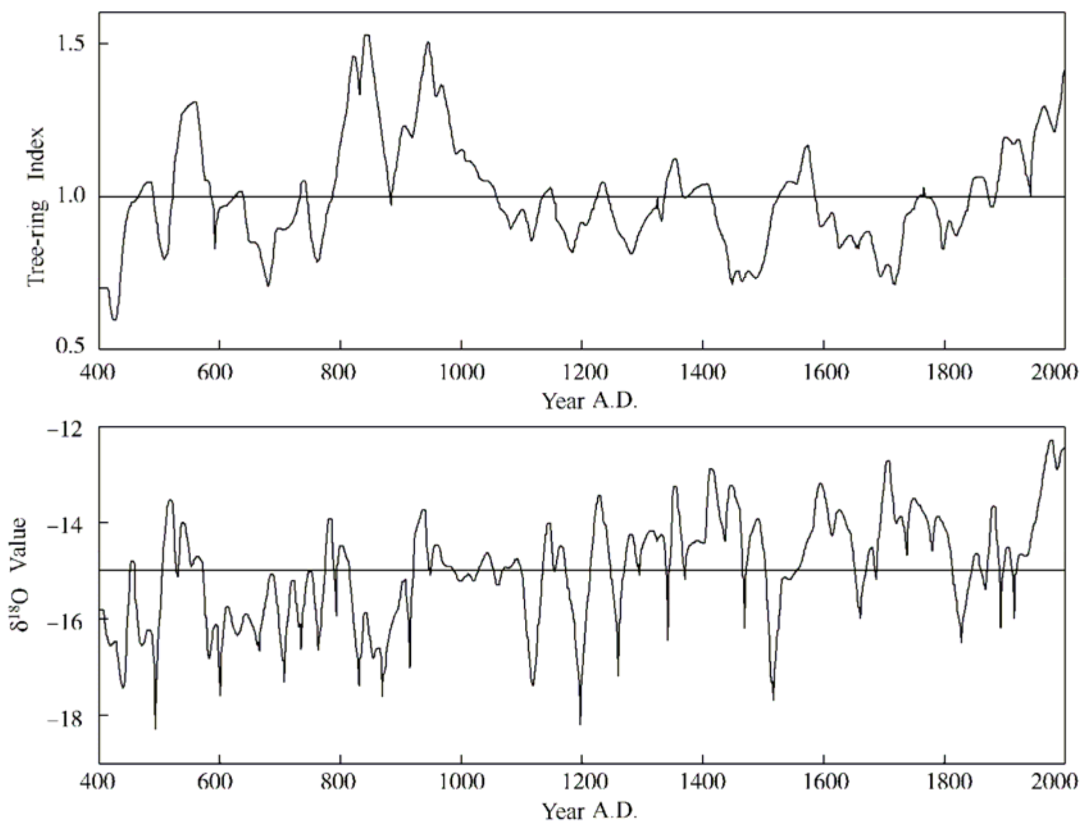

Figure 1.3. Tree-ring temperature index from Dulan County, Qinghai and $\delta^{18}O$ records from the Guliya ice cores, TAR.
Source: Yao, Yang, and Kang 2001.

Glacier net accumulation records from the Guliya ice cores indicate that 400-1400 A.D. was a dry period and that precipitation at Guliya did not begin to increase substantially until about 1200 A.D. (Fig. 1.4). After a roughly four-century increase in precipitation from 1200 to 1600, net precipitation at Guliya remained at a relatively high and stable level for about 200 years until the late 18th Century when a trend towards increasing aridity began (Yao, Yang, and Kang 2001; Yao, Thompson, Qin, Tian, Jiao, Yang, and Xie 1996). However, this decline in precipitation at Guliya was short-lived, with the 20th Century ushering in another wet period at Guliya (Fig. 1.4). Further research indicates that the low glacier accumulation periods recorded at Guliya closely correspond to dry periods in eastern China, while analysis of trans-Pacific precipitation patterns suggests a strong temporal correspondence between Guliya and the Quelccaya Ice Cap records from Peru (Thompson, Mosley-Thompson, Davis, Lin, Dai, Bolzan, and Yao 1995)

The indicators of temperature ($\delta^{18}O$) and precipitation (net accumulation) recorded in the Guliya ice cores show that on a long-term time scale, the temperature series is positively correlated to the precipitation series (Fig. 1.4). However, they are not synchronous on a relatively short time scale, which indicates

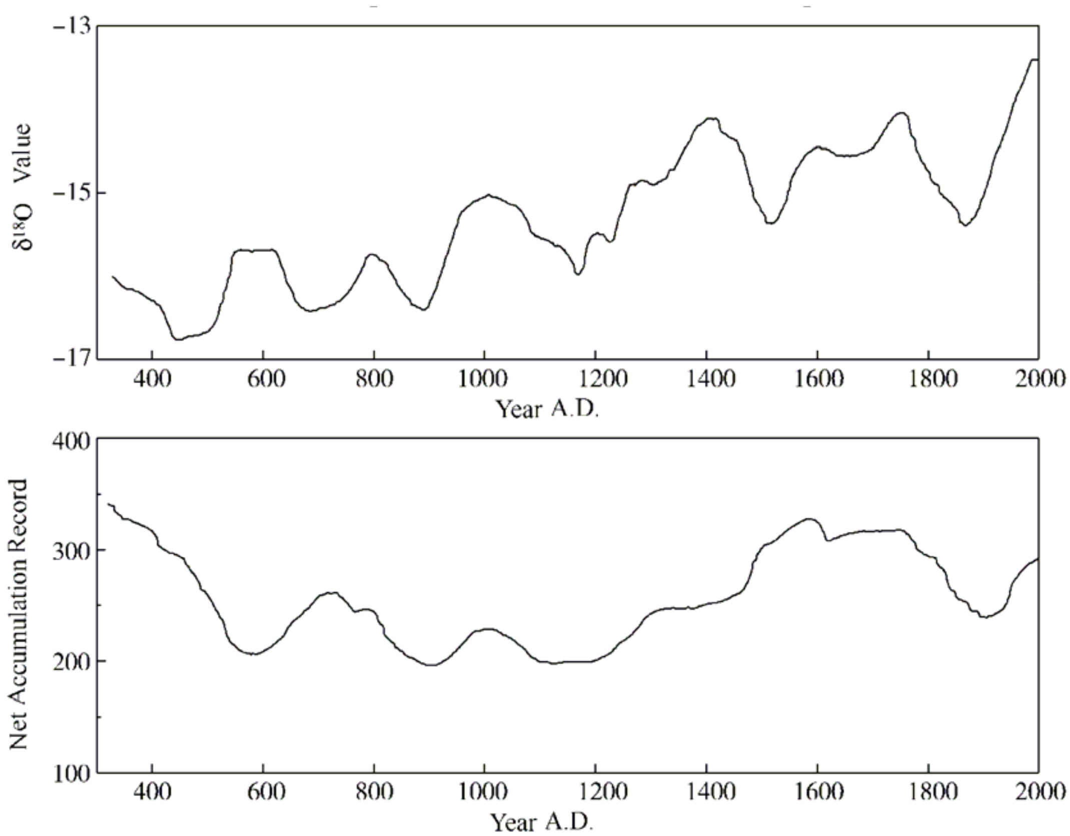

Figure 1.4. 11-point moving average of $\delta^{18}O$ and net accumulations records from the Guliya ice cores.
Source: Yao, Yang, and Kang 2001.

that patterns of cold and warm cycles alternated more frequently than those of precipitation. Although temperatures and precipitation correlate positively at a century scale, changes in precipitation lagged behind changes in temperature by about 50-100 years, which is most evident during periods of decreasing temperature (Yao, Yang, and Kang 2001).

1.3 Modern Meteorological Records of Climate Change on the Qinghai-Tibet Plateau

There were no meteorological observation stations on the Qinghai-Tibet Plateau until the 1950s, and even so, the spatial distribution of meteorological stations on the plateau continues to be sparse, particularly in the west of the plateau. As a result, the length of most instrumental climatic data is relatively short, and the accuracy of regional climatic series cannot be assured. The present distribution of meteorological observation stations on the plateau is shown in Figure 1.5 and a list

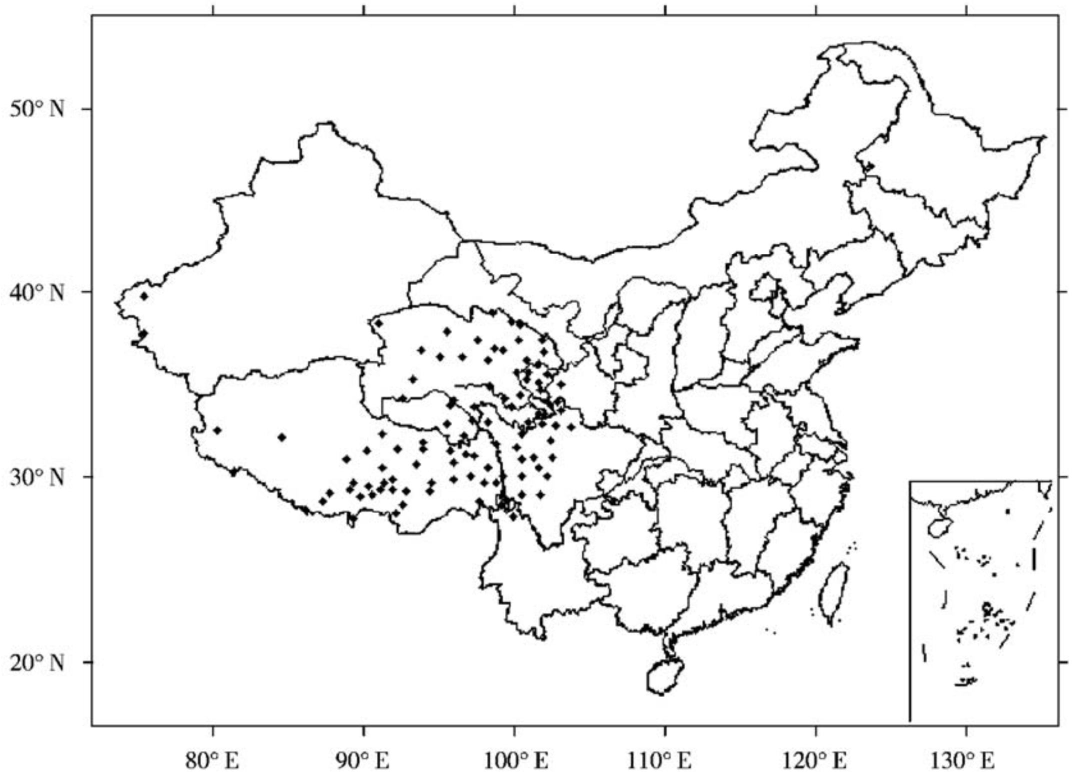

Figure 1.5. Present distribution of meteorological observation stations on the Qinghai-Tibet Plateau. Station names and locations are listed in Appendix C.

of all meteorological stations on the plateau and their locations is provided in Appendix C.

1.3.1 Temperature

As with most of the Northern Hemisphere, over the past half century a warming trend has been recorded at nearly all meteorological stations on the Qinghai-Tibet Plateau, although notably the Ganzi, Kangding, and Maerkang stations in western Sichuan have documented a significant local cooling trend over the same period (Liu and Chen 2000; Lin, Zhang, and Yin 2000; Lin and Zhao 1996). Figure 1.6 shows the annual mean surface temperature variation for the plateau from 1951 to 2004, which clearly illustrates the dramatic rise in temperatures since the 1980s. Analysis of available climate data indicates that during this period, the rate of warming on the Qinghai-Tibet Plateau has been about 0.17ºC/decade, and that the seven warmest of the last 54 years have occurred since the 1980s (Ren 2008).

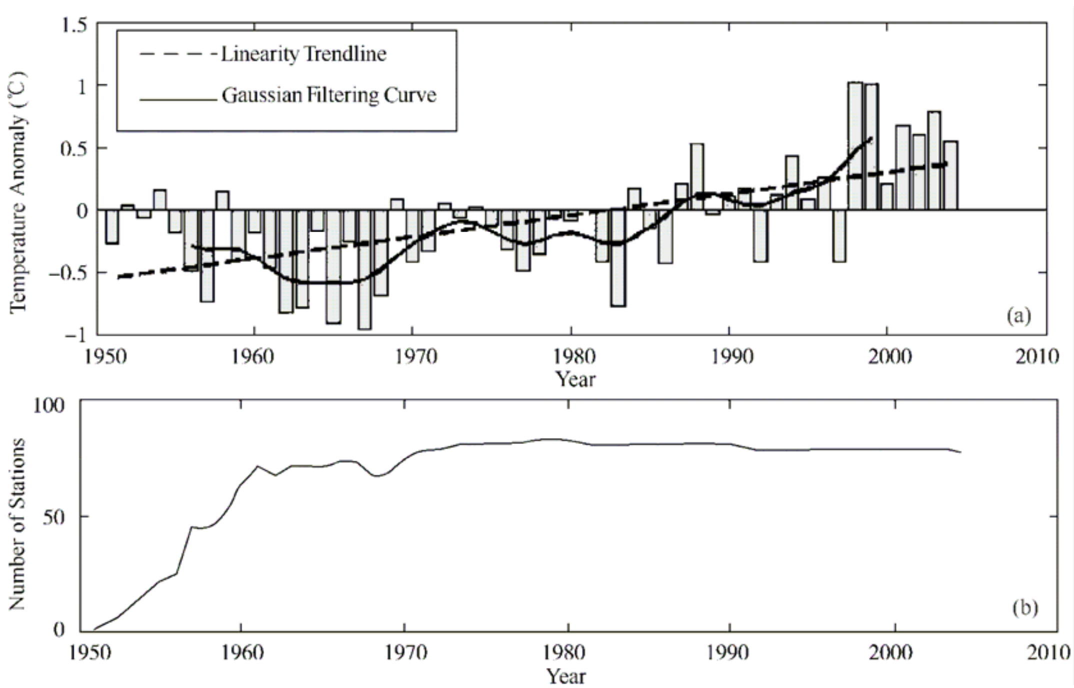

Figure 1.6. (a) Annual mean surface air temperature variation, and (b) the number of active meteorological observation stations on the Qinghai-Tibet Plateau.

Although the Qinghai-Tibet Plateau is experiencing a period of rapid warming, this warming is highly seasonal in nature. For example, at most plateau meteorological stations, winter temperatures have increased steadily in recent years and have the largest standard deviations, following a pattern similar to that for annual mean temperatures. Spring and autumn temperatures have also risen, although in a range with much smaller standard deviations than for winter temperatures. In contrast, summer temperatures, which have the smallest standard deviations, do not exhibit any obvious warming trends and have even decreased at some stations on the northeastern plateau (Lin, Zhang, and Yin 2000; Lin and Zhao 1996). In general, about three-quarters of the meteorological stations on the Qinghai-Tibet Plateau have shown a more prominent warming trend in winter than in summer (Lin, Zhang, and Yin 2000). At the same time, temperatures on the plateau appear to be rising more quickly in autumn than spring, which is one of the major differences between the climate trends of the plateau and those of eastern China and may be due to increasing snow cover on the Qinghai-Tibet Plateau in spring (Lin, Zhang, and Yin 2000; Liu and Chen 2000).

1.3.2 <u>Precipitation</u>

Precipitation on the Qinghai-Tibet Plateau decreases from a maximum in the southeast to a minimum on the western and northwestern plateau (Liu and Yin

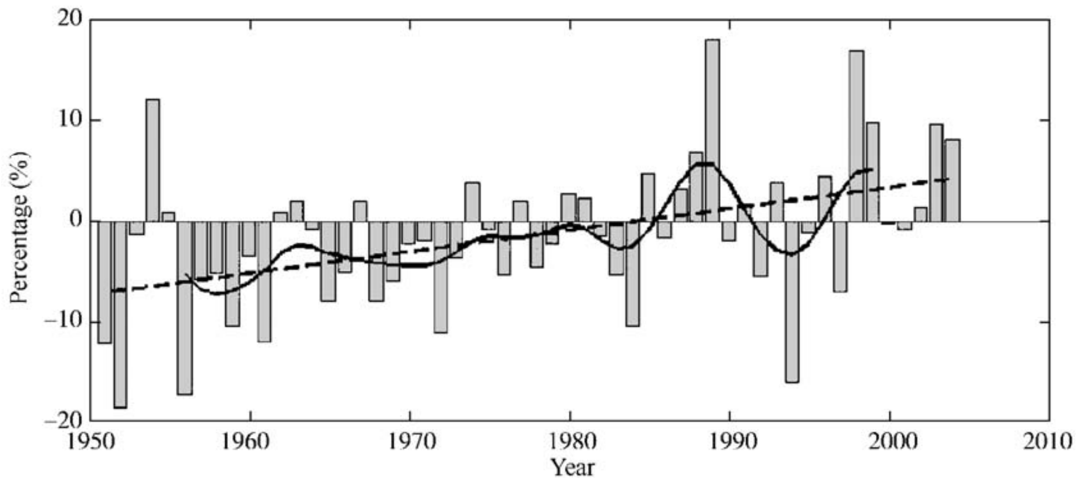

Figure 1.7. Annual precipitation anomaly on the Qinghai-Tibet Plateau, 1951-2004, as a percentage of annual mean precipitation for the period.

2001). At most plateau meteorological stations, precipitation is concentrated in summer when over 60 percent of annual precipitation occurs (Liu and Yin 2001). In general, because of the large regional variation in precipitation across the plateau, it is difficult to determine an accurate annual mean precipitation series for the entire plateau. However, after taking into account such factors as the particular station, data collection period, method of measurement, etc., it was possible to derive a annual mean precipitation series for the entire Qinghai-Tibet Plateau using an area-weighted, average-resolution method developed by Jones and Hulme, which indicates that precipitation on the plateau has increased slightly from 1951 to 2004 (Fig. 1.7) (Jones and Hulme 1996).

However, because the meteorological stations on the plateau are not evenly distributed, many uncertainties remain about any conclusions derived from Figure 1.7. On a station-by-station basis, only 45 percent of the plateau's meteorological stations recorded increases in precipitation, most of which are located in the vicinity of Nagchu in northern Tibet, on the northern slope of the Himalaya, and in the Yarlung Tsangpo-Lhasa-Nyang River basin (Photo 1.4) (Zhu, Chen, and Zhou 2001; Lin and Zhao 1996).

Photo 1.4. Mt. Everest (Qomolangma, Sagarmatha) and the crest of the Himalaya, TAR and Nepal. Photo by Dawa Tsering.

1.3.3 Temperature-Precipitation Related Climate Patterns

For many regions, characteristic climate patterns can be broadly described by their combined temperature and precipitation types. On the Qinghai-Tibet Plateau, these temperature-precipitation types are closely related to the source of moisture in a given area of the plateau, the three primary sources of moisture on the plateau being the Bay of Bengal, the Arabian Sea, and the central Indian Subcontinent (Fig. 1.8). Over the past half century, the Qinghai-Tibet Plateau has been principally dominated by both warm-dry and warm-wet type climates, while a cold-wet type climate has been observed in western Sichuan (Zhu, Chen, and Zhou 2001; Liu and Yin 2001; Lin, Zhang, and Yin 2000; Lin and Zhao 1996).

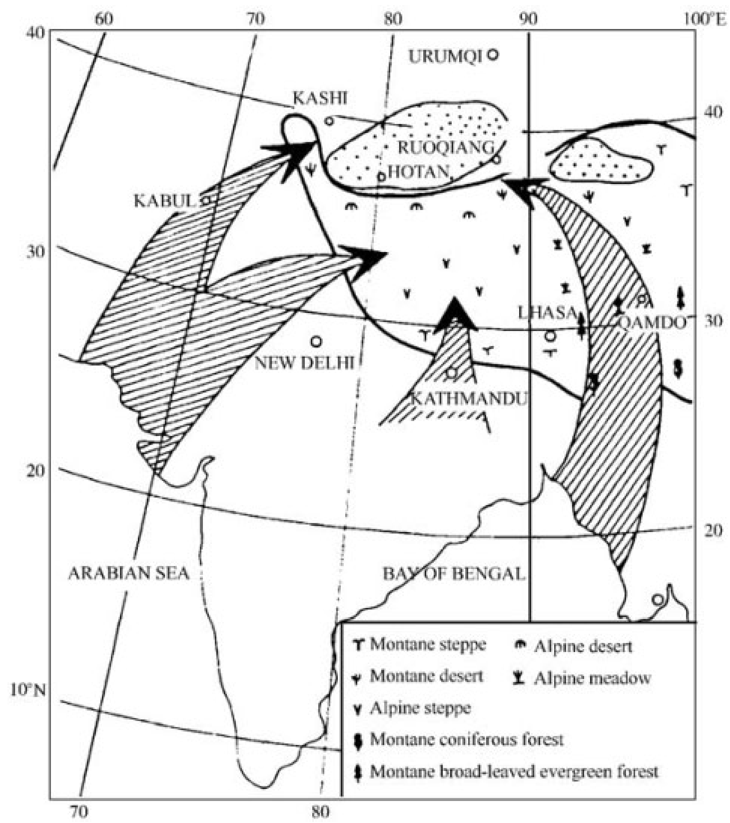

Figure 1.8. Sources of moisture and vegetation cover on the Qinghai-Tibet Plateau. Source: Lin, Zhang, and Yin 2000.

1.4 Correspondence of Regional Climate Change on the Qinghai-Tibet Plateau to Broader Global Warming Trends

An increasing body of scientific evidence clearly proves the existence of global warming. Recently a number of scientists have reconstructed the high-resolution

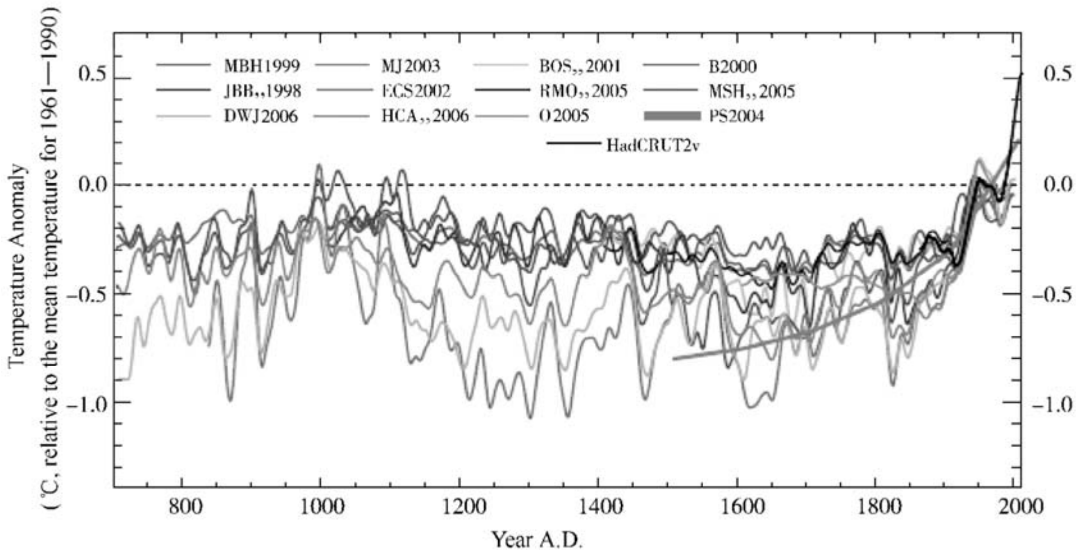

Figure 1.9. Reconstructed temperature series for the northern hemisphere over the past 2000 years as determined by various researchers.
Source: IPCC AR4 2007.

temperature series with millennium variation for the northern hemisphere over the past 2000 years, with most reconstructed series indicating that the rate of warming in the northern hemisphere in the late 20th Century has been unprecedented (Mann, Bradley, and Hughes 1999; Mann and Jones 2003). Below are reconstructed temperature series for the northern hemisphere presented in IPCC AR4 (Fig. 1.9).

1.4.1 Regional Variation in Temperature on the Qinghai-Tibet Plateau

Plateau temperatures have increased dramatically over the last 50 years, particularly since the 1980s, however, significant regional variations in climate trends on the plateau do exist (e.g. see Lin, Zhang, and Yin 2000). Some data indicate that the rate of warming on the plateau increases with increasing altitude, while other records show that southern Tibet began warming earlier than other areas of the plateau (Liu and Chen 2000; Lin and Zhao 1996). For example, the southeastern TAR was the first region of the plateau to experience significant warming in the early 1970s, followed by the TAR's eastern Yarlung Tsangpo River basin in the early 1980s. The western TAR, including Shiquanhe (capital of Ngari Prefecture) and Gerze County, was the last region of the plateau to experience increasing temperatures, not recording continuous warming until the late 1980s and early 1990s (Lin and Zhao 1996). Again, it should be noted that annual mean temperatures at the Ganzi, Kangding, and Maerkang Meteorological Stations in western Sichuan actually decreased over the same period, with significant cooling trends occurring in both winter and summer temperatures. But in general, the overall trend of continuous warming on the Qinghai-Tibet Plateau began first in the

southeast of the plateau and gradually spread north and westward over time (Lin, Zhang, and Yin 2000; Lin and Zhao 1996).

1.4.2 Comparison of Temperature Trends between the Qinghai-Tibet Plateau, Eastern China, the Northern Hemisphere, and Global Temperatures

To illustrate the different responses of the Qinghai-Tibet Plateau and eastern China to climate change, temperatures from the Lhasa, Beijing, and Shanghai Meteorological Stations were compared, while temperatures from these three stations were also compared to those for the northern hemisphere and the world as a whole (Table 1.1). From 1951 to 2002, the Lhasa station experienced two cold periods amidst the general warming trend. The first cold period occurred from 1959 to 1971, while the second occurred from 1977 to 1983, which was followed by a remarkable period of warming where the maximum temperature anomaly reached 1.7ºC with respect to the 1961-1990 climate reference period. When comparing Lhasa to Beijing and Shanghai, it was seen that the magnitude of warming at the Lhasa station was highest, while the temperatures at Shanghai showed the least variation over the 1951-2002 period. For the northern hemisphere, although the warming trend has been similar to that for the planet as a whole, the temperature curve shows a greater degree of fluctuation. Annual mean temperatures for the northern hemisphere were lower than those for the 1951-2002 climate reference period from 1951-1957 and also from 1964-1976. And it is not until 1978 that the annual mean temperature for the northern hemisphere finally exceeds the annual mean temperature for the 1951-1990 reference period, climbing well above it during the 1990s (Lin, Zhang, and Yin 2000).

Table 1.1 illustrates the general trend of warming in China and the world with respect to the 1951-1995 reference period, with there being significant positive relationships existing among all five temperature series that indicate simultaneous warming in all five series. At Lhasa, the annual temperature anomaly for the reference period increased at a linear rate of +0.0176ºC/year, while the average annual temperature anomaly for the period was 0.07ºC, which exceeded values for Shanghai, the Northern Hemisphere, and the world as a whole, only being surpassed by values for Beijing. At the same time, temperatures at Lhasa had relatively weaker correlation to the other four temperature series, with both the Beijing and Shanghai temperature series being better correlated to the northern hemisphere and global temperature series than Lhasa, while Beijing had the best correlation with the northern hemisphere and global temperatures series of the three selected cities. Taken together, these indices suggest that plateau and lowland stations are exhibiting different responses and sensitivities to global warming, although regional and altitudinal differences as well as human activities may also be possible causes of these differences. Finally, the relatively high standard deviations for annual temperature anomalies at Lhasa and Beijing indicate a considerable inter-annual variation in temperatures (Lin, Zhang, and Yin 2000).

Table 1.1 Statistical indices of the temperature anomaly series for Lhasa, Beijing, Shanghai, the Northern Hemisphere, and the world as a whole (Global) for the 1951-1995 annual mean temperature reference period

Temperature Series	Temperature Anomaly Correlation Coefficients					Related Statistical Indices		
	Lhasa	**Beijing**	**Shanghai**	**Northern Hemisphere**	**Global**	**Average Temperature Anomaly 1951-1995** (ºC)	**Standard Deviation**	**Linear Rate of Change of Temperature Anomaly** (ºC/year)
Lhasa	1.000	0.272	0.366*	0.307*	0.378*	+0.07	0.5214	+0.0176
Beijing	0.272	1.000	0.629**	0.701**	0.661**	+0.08	0.7711	+0.0273
Shanghai	0.366*	0.629**	1.000	0.562**	0.498**	+0.00	0.4805	+0.0131
Northern Hemisphere	0.307*	0.701**	0.562**	1.000	0.933**	+0.06	0.1791	+0.0063
Global	0.378*	0.661**	0.498**	0.933**	1.000	+0.04	0.1555	+0.0058

Note 1: * represents 95% confidence level; ** represents 99% confidence level.
Note 2: The closer the correlation coefficient is to 1, the stronger the correlation between the data sets, with a correlation coefficient of 1 indicating complete correlation between two data sets, while a correlation coefficient of 0 would indicate no correlation between data sets.
Note 3: The lower the standard deviation, the closer each point of an entire data set is to the mean value of that set, while a standard deviation of 0 would indicate that all data points have the same value.
Source: Lin, Zhang, and Yin 2000.

1.4.3 <u>The Role of the Qinghai-Tibet Plateau in the Global Climatic System and its Sensitivity to Climate Change</u>

Solar radiation on the Qinghai-Tibet Plateau is intense, leading to large diurnal temperature fluctuations. One result of this intense sunlight is the transfer of heat from the plateau surface to the atmosphere at a rate of about 340 cal/cm^2 per day, which has a tremendous impact on general atmospheric circulation (Yeh, Gao, Tang et al. 1979, cited in Ding 1992; Ye and Wu 1998; Kuang, Zhang, and Liu 2007). Thus, in summer the plateau is a huge source of heat, although being a source of cooling in late autumn and winter. Thermodynamic processes that include these seasonal changes in heat exchange, as well as broader regional differences in heating, not only set up the plateau monsoon but also strengthen the Asian monsoons, especially the East Asian winter monsoon (Ding 1992; Ye and Wu 1998). In addition, dynamic processes driven by the sheer height of the Qinghai-Tibet Plateau are another key factor affecting climate, with the physical obstruction of the plateau directly affecting many regional weather patterns, including the East Asian westerly jet stream and the East Asian trough (Ding 1992; An, Kutzbach, Prell, and Porter 2001; Kuang, Zhang, and Liu 2007). With respect to climate change, Kuhle has speculated that extensive glaciation in the Tibet and Himalayan region may have triggered a period of global cooling that resulted in the Pleistocene Ice Age, basing his theory on the unique combination of the plateau's low latitude,

extreme height, and the near total reflectance of incoming solar radiation that would have been caused by extensive glacier cover on the plateau during a cooler era (Kuhle 1987). In contrast, research now indicates that the widespread melting of snow and ice cover on the plateau due to the present climatic warming trend will significantly reduce planetary albedo, in turn accelerating warming on the plateau, particularly at higher elevations (Chen, Chao, and Liu 2003; Qu and Hall 2005).

Given these facts, many scientists are of the opinion that the Qinghai-Tibet Plateau is particularly sensitive to global warming (e.g. see Liu and Chen 2000; Yao Liu, Wang, and Shi 2000; Lin, Zhang, and Yin 2000). Over the past half century, temperature series show that climate warming has occurred both earlier and at a faster rate on the Qinghai-Tibet Plateau than in eastern, central, and southern China (Qian and Zhu 2001). Furthermore, temperature records since the 1970s indicate that the continental interior of Asia is one of the three sources of global climatic abnormality (e.g. extreme drought), with climatic abnormalities on the Qinghai-Tibet Plateau generally occurring about five years earlier than the regional mean (Lin, Zhang, and Yin 2000). In addition, both warm and cold periods recorded at the Lhasa Meteorological Station have appeared roughly five years earlier than in the Arctic, and thus may be regarded as a kind of early warning indicator for warming of the planet as a whole (Lin, Zhang, and Yin 2000). At the same time, some paleoclimatic proxy indicators, such as ice cores and lake sediments, also indicate that the impact of human-driven climate change is being magnified on the plateau (e.g. see Zhu, Chen, Li, Li, Xia, and Li 2002; Wang, Yao, Pu, Zhang, Sun, and Wang 2003; Yao, Thompson, Jia, Mosley-Thompson, and Yang 1995).

1.5 Conclusions

Due to the complexity of climate change and the lack of long-term meteorological data for the Qinghai-Tibet Plateau, many uncertainties exist in modelling the climate of the plateau and predicting future climatic changes. Thus, to date, the impacts of climate change on the Qinghai-Tibet Plateau cannot be projected with a high degree of accuracy, and many questions about the details of climate change and its impact on the plateau remain. However, the projections of the RegCM2 regional climate model indicate that doubling atmospheric carbon dioxide will increase temperatures on the plateau by 2.6-2.8ºC (Gao, Li, Zhao, and Giorgi 2003). Moreover, the IPCC AR4 report projects that, by the end of the 21st Century, temperatures on the Qinghai-Tibet Plateau will increase by 3.8ºC, a degree of warming much greater than that projected for the world as a whole, with the highest temperature increases occurring at the highest altitudes (IPCC AR4 2007). The report also states that winter precipitation is very likely to increase on the plateau.

It is believed that rapid warming at a global scale will accelerate the global water vapor cycle, which means that both evaporation and precipitation will increase in the future (IPCC AR4 2007). Over the past 100 years, the principal characteristic climate in northwestern China has been a warm-dry type climate. However, increasing evidence shows that strong warm-wet climate characteristics have already appeared in the western Tian Shan Mountains, as evidenced by meltoff of glaciers, increasing precipitation, rising lake levels, more frequent flood disasters, and less frequent cold weather and sandstorm events (Shi, Shen, Kang, Li, Ding, Zhang, and Hu 2007; Shi, Shen, and Hu 2002). Similar changes are also already occurring in parts of the Qinghai-Tibet Plateau, however, the question of whether the future climate of the plateau will be predominantly warm-dry or warm-wet is still the subject of heated debate.

With respect to conservation of high altitude wetlands on the Qinghai-Tibet Plateau, the future combined temperature-precipitation climatic type on the plateau, be it warm-dry or warm-wet, is perhaps the most important climatic factor that will determine the fate of the plateau's wetlands. For example, the water surface level of Qinghai Lake fell by 3.35 m between 1959 and 2000, which Li et al. attribute to the climatic trend towards increasing warmth and aridity in the Qinghai Lake region during this period, a situation that might be stabilized if precipitation in the region were to increase under a warm-wet climate scenario (Li, Xu, Sun, Zhang, and Yang 2007). One serious threat to the high altitude wetlands of the central Qinghai-Tibet Plateau's vast Yangtze, Yellow, and Mekong Rivers (Three Rivers) Source Region, which lies between the Tanggula and Kunlun Ranges, is that of permafrost degradation resulting from increasing temperatures. As temperatures in the Three Rivers Source Region rise, the thickness of the active layer overlying permafrost increases, permitting water to infiltrate deeper into the ground. So much so that it has been estimated that from 1990-2005, the area of high altitude wetlands in the Three Rivers Source Region decreased by 28 percent due to permafrost degradation (Wang, Li, Wu, and Wang 2006). This situation will only be further exacerbated should the climate of the region become increasingly arid. Thus, regardless of the form climate change ultimately takes on the Qinghai-Tibet Plateau, the impacts of global warming on the region's ecology and inhabitants will be profound, and improvements in the monitoring and modelling of climatic change on the plateau could make a large contribution towards developing an appropriate and effective adaptation strategy to deal with these changes.

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2

The Response of Qinghai-Tibet Plateau Lakes and Wetlands to Climate Change and Human Activities and the Implications for Biodiversity

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2.1 Introduction

The Ramsar Convention on Wetlands defines wetlands as being "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Ramsar 1971). Chinese scholars define wetlands as being "unique ecosystems composed of lands that have perennial or seasonal water seepage with a water depth of less than 2 m that can be found for periods of greater than four months per year, which support a surface water dependent biome" (Tong and Liu 1995, Zhao 1995). As determined by the plateau's main geomorphic and ecologic provinces, the wetlands of the Qinghai-Tibet Plateau can be divided into four broad types: shrubland wetlands, forest wetlands, riparian wetlands, and lake wetlands. Lake-type wetlands are the most important type of wetland found on the Qinghai-Tibet Plateau, occurring in large numbers that fill the otherwise barren basins of the central plateau, and include the ponded waters of river source areas, wet meadows, marshes, and bogs as well as lakes themselves.

2.2 Types of Lake Wetlands on the Qinghai-Tibet Plateau

2.2.1 River Source Area Wetlands

River source area type wetlands are widespread on the Qinghai-Tibet Plateau and are largely unique to the region. These include the highest and most extensive river source area regions on earth, such as the source regions of the Yangtze, Yellow, Mekong, Salween, Brahmaputra, Sutlej, and Indus Rivers. These riverhead regions have extremely large elevation ranges, cold climates, and are underlain by permafrost or seasonally frozen ground. Consequently, these conditions lead to the formation of broad, shallow seepage zones and ponds in flat, low-lying bottomlands where seepage, runoff, and snow and glacier meltwater are trapped (Photo 2.1). Due to the inherently cold climate in these locations, herbaceous vegetation growing in these boggy seepage wetlands does not fully decompose, leading to the formation of peat layers of varying depths. Eventually, circular grass hummocks form as a result of repeated freezing and thawing over many years, which often form minute "islands" surrounded by seasonally frozen ponds (Photo 2.2). Representative vegetation of these river source area wetlands include various sedge grass species of the genera *Kobresia* and *Carex*, which form the basis of ecologically unique plant communities in these high altitude wetlands.

Photo 2.1. River source area wetland, Shenzha County, Chang Tang Region, TAR. Photo by John D. Farrington.

2.2.2 Wet Meadows

Wet meadow type wetlands are the most widely distributed type of wetlands on the Qinghai-Tibet Plateau. Following the retreat of quaternary glaciers, numerous small lakes and ponds were formed in low-lying areas across the Qinghai-Tibet Plateau, most of which evolved into wet meadows due to their limited depth although some continue to exist as shallow lakes. These wet meadows have a wide distribution on the plateau and are found beside lakeshores, in intermontane basins, along riparian corridors, atop groundwater seepage fields in mountain piedmont areas,

Photo 2.2. Wet Meadows, Longbaotan National Nature Reserve, Jyekundo County, Qinghai. Photo by Yifei Zhang.

below glacier fields in alpine areas, and in saddles along watershed divides (Photo 2.2). Vegetation in wet meadow wetlands is dominated by various types of sedge grasses, such as *Kobresia tibetica*, which is widely distributed and the most representative type of wetland plant on the northern Qinghai-Tibet Plateau (Wang and Wang 2003). Other notable plateau sedge grass species include *Kobresia kansuensis*, which on the Qinghai-Tibet Plateau is restricted to mountain saddles and piedmont seepage areas with an altitude range of 3800–4700 m in Yushu and Golog Prefectures of Qinghai Province, and *Kobresia littledalei*, which is found widely distributed from the Tanggula Range of southwest Qinghai to the Zoige Wetlands of northern Sichuan as well as at Xingxiu Hai Lake in central Qinghai Province, Mugxung Township in southern Qinghai Province, around lakes in the southern Tibet Autonomous Region (TAR), and in riparian areas of the TAR's upper Yarlung Tsangpo River basin (Wang and Wang 2003).

2.2.3 <u>Marshes</u>

Marsh type wetlands are characterized by abundant emergent vegetation, periodic or permanent shallow water, mineral soils, and little or no peat deposition and derive most of their water from surface water (EPA 2002). Marshes typically occur in the shallow areas of lakes and slow-flowing rivers and differ from wet meadows in that they have deeper water with higher flow volumes and more highly developed vegetation. The most extensive areas of marsh wetlands on the Qinghai-Tibet Plateau occur along the waterways and lakes of the Zoige Wetlands, which are typified by abundant growth of sedge grass species such as *Kobresia tibetica* and *Carex muliensis* (Photo 2.3) (Li and Zhou 1998).

Photo 2.3. Greylag Geese, Zoige Marshes, Zoige County, Sichuan. Photo by David Blank, GEF Project CPR/98/G32, Wetlands Biodiversity Conservation and Sustainable Use in China.

2.2.4 <u>Bogs</u>

Bog type wetlands are waterlogged peatlands in old lake basins or depressions in the landscape where, due to climatic conditions, accumulation of plant matter exceeds decomposition (NCSU 2003). While elsewhere in the world bogs are dominated by woody vegetation, on the Qinghai-Tibet Plateau "grass bogs" occur. Perhaps the most high profile of the plateau's bog wetlands is the Lhalu Wetland National Nature Reserve located within the Lhasa city limits (Photo 2.4). The Lhalu

Wetland is classified locally as a "reed peat bog" and is dominated by common reeds (*Phragmites australis*), various sedge grass species, such as *Kobresia schoenoides*, as well as the emergent macrophyte calamus (*Acorys calamus*) (LWNNR 2005).

Photo 2.4. Reed bog (*Phragmites australis*), Lhalu Wetland National Nature Reserve, Lhasa, TAR. Photo by John D. Farrington.

2.2.5 Lake Basins

Lake basin type wetlands on the Qinghai-Tibet Plateau are typified by the numerous large lakes scattered across the plateau that form one of the densest concentrations of lakes in China (Photo 2.5). As determined using satellite images, there are a total of 1091 lakes with surface areas greater than one km^2 on the plateau that have a combined surface area of 44,993 km^2, or 49.5 percent of China's total lake surface area, giving the Qinghai-Tibet Plateau the most extensive high altitude lake and wetland complex on earth (Wang and Dou 1998). The occurrence of high concentrations of lakes on the Qinghai-Tibet Plateau can be divided into five broad regional lake clusters, in the Chang Tang Region, the Qaidam Basin, the Karakorum-Kunlun region, and lake clusters concentrated on the eastern and southern plateau. The largest of the plateau's many lakes is the 4400 km^2 Qinghai Lake in northeast Qinghai Province (see Appendix D for a list of lakes in the Yangtze Source Region).

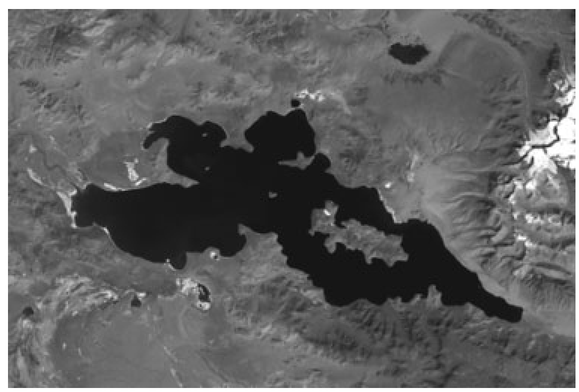

Photo 2.5. Ngangla Ring Co Lake, Shigatse Prefecture, TAR. NASA Landsat Image.

The are two primary reasons behind the formation of large lake clusters on the Qinghai-Tibet Plateau: 1) the formation of vast closed basins in the Chang Tang and Qaidam Regions of the plateau and 2) extensive quaternary glaciation of the plateau that left widespread water-filled depressions upon glacial retreat (Chen 1981). As a result of these tectonic and glacial processes, numerous large lakes were formed, and today many of these lakes are surrounded by extensive wetlands that have evolved ecosystems unique to the Qinghai-Tibet Plateau. The majority of lakes on the plateau are saline, however, all lakes on the plateau provide vital ecosystem services, such as creating habitats that are zones of high biodiversity;

moderating microclimates; absorbing lead, mercury, and other contaminants through the deposition of sediments; storing and regulating water supply; and contributing to the overall maintenance of regional ecological balance.

2.3 Holocene Changes in Lake Surface Levels on the Qinghai-Tibet Plateau

Each lake on the Qinghai-Tibet Plateau has a unique natural history, however, although some lakes expanded during the Holocene, the vast majority ultimately decreased in size. In the process, many of these shrinking lakes were transformed from being ocean-flowing to closed-basin lakes that are becoming increasingly saline as time passes. Lake level fluctuation during the Holocene on the Qinghai-Tibet Plateau can be divided into three broad periods, discussed below (Shi, Li, and Li 1998).

2.3.1 <u>Early Holocene: 10,000-7500 ybp – Freshwater lake period</u>

During the Early Holocene, lakes on the Qinghai-Tibet Plateau were nearly all freshwater. Many presently saline lakes in the west, south, and southeast of the Chang Tang Region had much higher water surface levels than at present, and consequently were outflowing freshwater lakes. The highest Holocene lake surface levels for Qinghai Lake in the northeast of the plateau and Bangong Co Lake in the far west occurred at about 10,000 and 9000 ybp, respectively, while Sumxi Co Lake in the western TAR formed a lakeshore terrace 30 m above the present lake level at about 8850 ± 170 ybp. Collectively, these high lake levels indicate higher precipitation in both the east and the west of the plateau during this period. Yet at the same time in the TAR's Chang Tang Region, Chabyer Caka, Chagcam Caka, and Bangkog Lakes, among others, were beginning to evolve into saline lakes, while saline lakes were also beginning to appear on the dry salt flats of the Qaidam Basin (summarized from Shi, Li, and Li 1998).

2.3.2 <u>Middle Holocene: 7500-3000 ybp – Lake surface levels rise</u>

The Middle Holocene was characterized by a warm, humid climate, and as a result, the surface levels of most lakes rose and lake surface areas expanded. The water of lakes on the Qinghai-Tibet Plateau became increasingly fresher, while many lakes in the center and south of the plateau developed third-level lakeshore terraces. Carbon-14 dating of peat and snail shells found in sediments on third-level terraces indicates that these terraces developed between 7500 and 3000 ybp, e.g. in the TAR at Zhari Namco Lake at about 7010 ± 150 ybp, at Nariyong Co Lake between 6380 ± 100 and 3625 ± 100 ybp, at Pelku Co Lake at roughly 6325 ± 200

ybp, and at Chen Co Lake at about 3050 ± 150 ybp. By comparing the height of third terraces and the height of former lake outflow channels, it can be shown that almost every lake in the south of the Qinghai-Tibet Plateau was outflowing or flowed to a neighboring lake at this time. The degree of mineralization of some lakes was much lower than today, such as at Zhari Namco, where mid-Holocene sediment samples all contain the freshwater-dwelling snail *Radix auricularia* Linneaus, although the degree of mineralization of the lake's water is now 14.895 g/l. Seling Co Lake in the central TAR had its highest lake surface levels between 8400 and 5500 ybp, indicating a much wetter climate during this period (Photo 2.6). Chabyer Caka Lake formed a fourth terrace between 7700 and 6800 ybp when water level increased above the previous terrace level, with salinity of the lake simultaneously decreasing slightly, a further indication of a wetter climate at this time.

Photo 2.6. Co Ngoin (foreground) and Seling Co Lakes, Shenzha County, Chang Tang Region, TAR. Photo by John D. Farrington.

At Qinghai Lake, a series of lakeshore terraces formed roughly 7000 to 3500 ybp that range from 25-65 m higher than the present lake level (Photo 2.7). During this period, a lakeshore terrace was formed 46 m above present lake level in the Daotanghe River Valley on the southeast corner of Qinghai Lake, while on Haiyan Bay in the northeast corner of the lake, a shoreline 50 m higher than the present lake surface probably formed at about the same time. Gounong Co Lake in the Hoh Xil region of western Qinghai had a larger surface area and was less mineralized before about 5500 ybp, after which the lake began to shrink and become increaseingly saline. Bangong Co Lake expanded until about 6000 ybp, with sediments from this period having been dated at 6750 ± 170 ybp, after which time the lake's surface level began to fall with the lake becoming increasingly saline. Analysis of Bangong Co Lake sediment cores indicates that the climate of the Holocene was dry until 9600 ybp and humid and warm from about 9600-3800 ybp, with the climate having been wetter before 6300 ybp than at present and only one major dry period occurring from about 5700-5200 ybp (summarized from Shi, Li, and Li 1998).

Photo 2.7. Qinghai Lake (Koko Nor), Qinghai Province. NASA Landsat image.

2.3.3 Recent Holocene: 3,000 ybp to the Present – Saline lake period

During the Recent Holocene, nearly all lakes on the plateau decreased in size with their lake surface levels falling rapidly at times. From analysis of former lake shorelines in the southern Chang Tang and south of the plateau, it can be seen that lake levels have periodically dropped 10-20 m as indicated by terrace levels along lakeshores and in lake estuaries. With the drying up of larger lakes, several isolated smaller lakes were often created, such as when Yamdrok Co, Chen Co, and Bajiu Co Lakes in the southern TAR were created from the same parent lake during this period (Photos 2.8 and 2.9). Yamdrok Co was also transformed from being an out-flowing lake to a closed-basin lake as was Pelku Co. Because of continuously falling lake levels, most new closed-basin lakes quickly became saline, although the most recently formed closed-basin lakes in the southern TAR still remain fairly fresh for the time being.

The recent Holocene has been the main period of increasing lake salinity on the Qinghai-Tibet Plateau, which is a reflection of increasing aridity during this period. Analysis of lake sediment cores has revealed that particularly arid periods occurred at Bangong Co and Sumxi Co Lakes from about 3900-3200 ybp, at Seling Co Lake in the central plateau after 4200 ybp, and at Qinghai Lake in the east of the plateau since about 3000 ybp (summarized from Shi, Li, and Li 1998).

Photo 2.8. Yamdrok Co Lake, Lhoka Prefecture, TAR. Photo by Dawa Tsering.

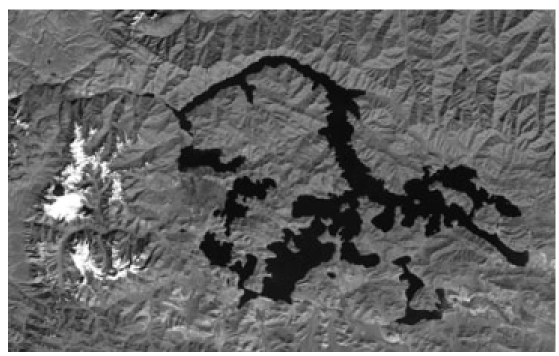

Photo 2.9. Yamdrok Co (largest lake), Chen Co (center), and Bajiu Co (lower right) Lakes, Lhoka Prefecture, TAR. NASA Landsat image.

2.4 Holocene Changes in Peat Deposition on the Qinghai-Tibet Plateau

Peat formation is a result of paleobog deposition. As with changes in lake levels, stratigraphic analysis and carbon-14 dating of Holocene peat deposits reveals that the recent formation of peat on the Qinghai-Tibet Plateau can be divided into three periods, discussed below (Zhu and Li 2003).

2.4.1 Early Holocene: 10,000-7500 ybp – Formation of peat deposits begins

The initiation of peat deposition in this period can be seen at two sites in the Yangpachen-Damshung Basin, located on the southern plateau in the TAR's Lhasa Municipality. Damshung County's Wuma Chu River Peat Deposit is about 2 m thick, with carbon-14 dating showing the bottom of the deposit to have been formed about 9970 ± 135 ybp and the top 3575 ± 80 ybp. The Qinongza Peat Deposit, located near Damshung County's Yangpachen Township, is about 3 m thick, with the bottom of the deposit having been formed about 8175 ± 200 ybp and the top about 3050 ± 200 ybp. In the Zoige Basin on the northeastern plateau, which overlaps Sichuan's Zoige County and Gansu's Machu County, the formation of peat began about 12,000 ybp, with the maximum period of peat production having been about 3500 to 1000 ybp (research site location: 33°37' N, 102°56' E) (Photo 2.10). Notably, however, peat deposits in the Zoige Basin are thinner than in the Yangpachen-Damshung Basin, and are interbedded with layers of granular sediments. This suggests that the climate at Zoige was rather cold in the early Holocene and the development of bog vegetation was fairly constrained (summarized from Zhu and Li 2003).

Photo 2.10. Eastern Zoige Wetlands, Yellow and Bai He (lower right) Rivers, Machu County, Gansu Province, and Zoige County, Sichuan Province. NASA Landsat image.

2.4.2 Middle Holocene: 7,500-3,000 ybp – Period of maximum peat production

Peat deposition during this period was widespread, leading to formation of rather thick peat layers. The Wuma Chu River Peat Deposit shows no obvious boundary between early and middle Holocene peat deposition, which indicates that the climate grew warmer and wetter during this period, and consequently more conducive to the growth of the large amounts of wetland plants needed for the formation of peat. In addition to the three peat deposits discussed above, a number of other grass peat deposits dating from the middle Holocene have been documented in the TAR, including the Bangdag Co Lake Peat Deposit, formed 7670 ± 250 ybp; the Sipanguer Lake Peat Deposit, formed 4525 ± 120 ybp; the Ngangla Ring Co Lake Peat Deposit, formed 4070 ± 160 ybp; and the peat deposit on the west shore of Doqen Co Lake, formed 3930 ± 250 ybp (Photo 2.5) (summarized from Zhu and Li 2003).

2.4.3 Late Holocene: 3,000 ybp to the Present – Peat production declines

During this period, peat production on the Qinghai-Tibet Plateau underwent a universal decline, with the formation of peat in some areas completely ceasing, such as in the Wuma Chu River basin in Damshung. In other areas, the mud and gravel content in peat increased dramatically, such as in the Qinongza Peat Deposit. The decline of peat production on the plateau at this time is indicative of decreases in both temperature and precipitation in the late Holocene, as the plateau climate became colder and drier (summarized from Zhu and Li 2003).

2.5 Climate Change Reflected by Lake Records in the Historical Period on the Qinghai-Tibet Plateau

There are many lake clusters stretching across the Qinghai-Tibet Plateau which have some of the highest altitudes, largest numbers, and largest surface areas of any of the earth's lake regions, most of which are closed-basin lake clusters located in the vast interior of the plateau. During the historical period, the plateau's lake basins have undergone a variety of dramatic climatic and environmental changes. Study of these changes as recorded in lake sediments reveals not only natural climatic and environmental changes, but also changes induced by more recent human activities, thus illustrating some of the ways in which humans affect the natural environment.

Reconstruction of climatic change through high resolution analysis of climate change indicators found in lake sediments, such as total organic carbon, total nitrogen, diatoms, pollens, ostracods, and various biomarkers, is the primary means for studying climate change during the historical period on the Qinghai-Tibet Plateau. The present review focuses on three regions: 1) the lakes of the central and southern plateau, 2) the marginal zone in the northeast of the plateau, and 3) the west Kunlun Range lake cluster on the western Plateau. The time scale covered by this study is roughly the past 2800 years, with sediments having been analyzed at a resolution of about 10 years.

2.5.1 Environmental Change Recorded by Lake Sediments on the Central and Southern Plateau

Due to its high altitude and numerous soaring mountain ranges that act as atmospheric barriers, the climate of the central Qinghai-Tibet Plateau is only influenced by the later part of the East and South Asian monsoons. The southern plateau lies in the rain shadow of the Himalaya and is thus not significantly influenced by the South Asian monsoon until after it crosses the Himalaya in early summer.

Consequently, climatic changes as evidenced by periodic changes in lake sediments show regional variation between central and southern Tibet.

Analysis of sediments from Co Ngoin Lake in the central TAR yields a record of environmental change for the last 200 years (Photo 2.6). Results indicate that climatic change on the central Qinghai-Tibet Plateau occurred in two phases during the past two centuries, with the 19th Century having been arid with shallow bog type deposition occurring, while both temperature and humidity increased during the 20th Century, indicating a transition to a lake-type depositional environment (Wu, Wang, Xia, Li, and Luecke 2003). This 20th Century variation in humidity occurred in roughly 20 year cycles, with the periods from 1920-1940 and 1960-1980 having been particularly wet periods, while the region around the lake has been becoming increasingly arid since 1980.

The sediment record from Chen Co Lake in the southern TAR yields climatic and environmental change information for the last 1400 years (Photo 2.9). A study of environmental magnetism in Chen Co Lake sediments has shown that there were three warm periods that occurred in the region during this period, from 620-740 A.D., 1120-1370 A.D., and from about 1900 A.D. to the present, while cold periods occurred from 740-1120 A.D. and from 1550-1690 A.D. (Zhang, Xia, Li, and Chen 2003). The warmest period of this fourteen century record was from 1120-1370 A.D., while the coldest was from 1550-1690 A.D., after which a long cold-wet period occurred from 1690-1900 A.D., which was followed by the present warm-dry period. Analysis of ostracods and sediment grain size show that Chen Co Lake was a deep lake prior to 1370 A.D., but afterwards became increasingly shallow until the late 19th Century (Zhu, Li, and Li 2002). Subsequently, Chen Co Lake's water level began to rise again in the 1930s, but later began to fall rapidly during the 1980s (Zhu, Li, and Li 2002).

2.5.2 Environmental Change Recorded by Lake Sediments on the Northeastern Plateau

The northeastern margin of the Qinghai-Tibet Plateau forms the boundary between the second and third level of hypsography in China, with most of the region having elevations ranging from 2000-4000 m. Although the northeastern plateau is the terminal zone of influence of the East Asian monsoon, the climate in the region is also influenced by the South Asian monsoon and the prevailing westerlies, making the region very sensitive to climatic change. The region straddles the upper Yellow River basin and has experienced both the advance and retreat of local glaciers, thus it is suitable for the study of climatic and environmental change on the plateau. In addition to the upper Yellow River, other notable geographic features of the region include the saline Qinghai Lake, the largest lake on the Qinghai-Tibet Plateau, and the vast Zoige Wetlands.

The sediment record from Ximen Co Lake, located in southeast Qinghai's Jigdril County, indicates that this area has experienced a warming trend as a whole over the last 2800 years, which can be divided into 4 distinct periods: two warm-dry periods from 780–430 B.C. and 480–1460 A.D., and two cold-wet periods from 430 B.C.–480 A.D. and 1460–1900 A.D. (Wang, Xue, and Xia 1997). The sediment record from Qinghai Lake indicates that in the most recent 1000 year period, there were five cold-wet periods that alternated with five warm-dry periods, with the warm-dry periods having occurred at about 1200 A.D., 1400 A.D., 1600 A.D., 1750A.D., and 1960 A.D. (Shen, Zhang, and Xia 2001).

In the Zoige Basin, a study of sediments from Xing Co Lake indicates that there were three distinct periods of highly variable mid-summer temperatures and annual precipitation totals that occurred during the last 200 years. From 1820-1892, mid-summer temperatures varied from 4-6.5ºC, while total annual precipitation varied from 357-636 mm; from 1892-1952, mid-summer temperatures varied from 2.1-6.8ºC, while total annual precipitation varied from 303-643 mm; and from 1952-1995, when mid-summer temperatures varied from 5.9-9.1ºC, while total annual precipitation ranged from 222-483 mm. In the mid- and late 19th Century, total annual precipitation was about 220 mm higher in the Zoige Basin than at present, while mid-summer temperatures were about 2ºC lower than today. However, during the 1940s, the period of maximum temperature decrease in the 20th Century, total annual precipitation and mid-summer temperatures in the basin were 60 mm lower and 3ºC cooler, respectively, than at present (Wu, Schleser, Luecke, and Li 2007). In general, though, the climate in the Zoige Basin has exhibited a clear trend of warming and drying over the last 50 years.

2.5.3 Environmental Change Recorded by Lake Sediments on the Western Plateau

The lake cluster at the southern foot of the western Kunlun Range in the northwest corner of the TAR has altitudes generally ranging from 4800–5100 m. In this region, the East and South Asian monsoons are largely obstructed by high mountains, thus climate in the region is primarily controlled by the prevailing westerlies of the upper atmosphere. This region is the coldest and driest on the Qinghai-Tibet Plateau, therefore, the lake sediments found here are highly indicative of climatic and environmental change. Rutok County's South Hongshan Lake provides a high resolution record of climatic change over the past 150 years, which indicates that the climate of the region was cold and wet in latter half of 19th Century, warm and wet between the late 19th Century and the 1920s, and has become increasingly warmer and drier since the late 1920s (Zhu, Chen, Li, Li, Xia, and Li 2002).

Thus, a comprehensive analysis of lake sediment records from different areas of the Qinghai-Tibet Plateau over the last 2800 years indicates that the climate was initially warm and dry for the first three and a half centuries of this period, followed

Table 2.1 General climatic periods on the Qinghai-Tibet Plateau, 780 B.C. to the present, as determined by analysis of lake sediments

Time Period	Duration of Period (years)	General Climatic Trend
780–430 B.C.	350	Warm and Dry
430 B.C.–480 A.D.	910	Cold and Wet
480–1460 A.D.	980	Warm and Dry
1460–1900 A.D.	440	Cold and Wet
1900–Present	110	Warm and Dry

Source: Compiled from Wang, Xue and Xia 1997; Zhu, Zhang, Xia, Li and Chen 2003; and Wu, Schleser, Luecke and Li 2007.

by a nine-century cold-wet period, a second warm-dry period lasting ten centuries, a second cold-wet period lasting five and a half centuries, and finally a period of general warming and drying from the beginning of the 20th Century to the present day (Table 2.1) (Wang, Xue and Xia 1997; Zhu, Zhang, Xia, Li and Chen 2003; Wu, Schleser, Luecke and Li, 2007). The climatic shift from a cold-wet climate to the present warm-dry climate that occurred on the plateau in the early 20th Century is clearly reflected in lake sediment records and indicates that along with the temperature increases of the past century, the climate of the plateau has also become increasingly more arid. In general, the increasing aridity of the Qinghai-Tibet Plateau in the late 20th Century has resulted in a widespread decrease in the depths and surface areas of lakes on the plateau as well as a large-scale drying up of wetlands surrounding these lakes. However, with the rapid increase in temperatures on the plateau since the 1980s, many lakes which are fed by glacial meltwater have actually been increasing in depth and size since the 1990s, a result of the accompanying rapid meltoff of the plateau's glaciers (Wu and Zhu 2008). Nevertheless, these increases in lake depths and surface areas are only expected to be temporary, and will be quickly reversed as the glaciers that feed these lakes begin to disappear in coming decades.

2.6 Flora and Fauna of Qinghai-Tibet Plateau Wetlands

2.6.1 Plateau Wetland Vegetation

There are a wide variety of alpine wetland plants that occur in the Qinghai-Tibet Plateau's wetlands, lakes, and rivers. According to field surveys and quadrat investigations in Qinghai Province, there are 428 species of higher plants that occur in Qinghai's wetlands which are comprised of 39 families and 146 genera (Chen, Huang, Lu, and Peng 2002). However, wetland plant communities on the Qinghai-Tibet Plateau are dominated by various sedge grass species of the genera *Kobresia* and *Carex*, which are by far the most common plant types found in plateau wetlands. Types of wetland vegetation on the plateau can be broadly categorized as submerged plants, emergent plants, and wet meadow vegetation.

2.6.1.1 Submerged Plants

Submerged plants are widely distributed in alpine aquatic environments of the Qinghai-Tibet Plateau, such as in ponds, marshes, bogs, the littoral zones of alpine lakes, backwater areas of rivers, and slow flowing streams. Dominant species of submerged plants in plateau wetlands include *Potamogeton pectinatus*, *Batrachium bungei*, and *Myriophyllum spicatum*, which usually occur in strips in the shallow areas of lakes and rivers. These submerged plant communities are usually composed of a single species but sometimes are found together with emergent water plants, such as *Phragmites australis*, *Eleocharis* spp., *Catabrosa aquatica*, *Scirpus tabernaemontani*, *Hippuris vulgaris*, *Triglochin palustre*, *Halerpestes tricuspis* and others (Chen, Huang, Lu, and Peng 2002).

2.6.1.2 Emergent Plants

As with submerged plants, emergent plants are also widely distributed in aquatic environments, such as in wet meadows, marshes, ponds, bogs, littoral zones of alpine lakes, slow flowing streams, and back water areas of rivers. Emergent plants are generally rooted in saturated soils composed of peat or silt with high humus content and on the Qinghai-Tibet Plateau are predominantly various sedge and reed species, such as *Kobresia* spp., *Carex orbicularis*, *Scirpus tabernaemontani*, *Typha angustifolia*, *Hippuris vulgaris*, and *Phragmites australis*. These plants typically reproduce by cloning through rhizomes, which usually results in them forming a blanket distribution where they occur. The dominant species of emergent plant in alpine wetlands varies by both region and altitude, with the dominant emergent species in the wetlands of the Qaidam Basin being primarily *Hippuris vulgaris*, while in the source areas of the Yangtze and Yellow Rivers dominant emergent plant species include *Hippuris vulgaris*, *Carex orbicularis*, *Kobresia* spp., and other sedge species. These emergent plant communities usually occur with other wetland plants, such as *Potamogeton pectinatus*, *Myriophyllum spicatum*, *Batrachium bungei*, *Halerpestes tricuspis*, *Catabrosa aquatica*, *Carex* spp., *Eleocharis* spp., *Scirpus distigmaticus*, *Triglochin palustre*, and *Phragmites australis*, which collectively may make up 35 to 85 percent of total plant cover in plateau wetland communities where emergent plants occur (Chen, Huang, Lu, and Peng 2002).

2.6.1.3 Wet Meadow Vegetation

Wet meadows on the Qinghai-Tibet Plateau are widely distributed along lakeshores, river floodplains, poorly drained bottomlands, intermontane basins, bogs, and other places that are seasonally saturated. Plateau wet meadows have peaty soils and are dominated by perennial herbaceous species that reproduce through rhizomes, such as *Kobresia schoenoides*, *Carex stenophyloides*, and *Blysmus sinocompressus*, the root systems of which are densely interlaced, leading to blanket distribution of these species in association with other wetland or alpine meadow plant species. There are numerous other plants typical of these high altitude wet meadow communities, including *Carex atrofusca*, *C. moocroftii*, *Kobresia pygmaea*, *Poa calliopsis*, *Caltha scaposa*, *Ranunculus nephelogenes*, *Primula nutans*, *Glaux maritime*, *Gentiana leucomelaena*, *Pedicularis longiflora* ssp.

tubiformis, *Aster flaccidus*, and *Cremanthodium brunneopilosum*, which collectively may account for 75 to 95 percent of all plant cover in wet meadows (Chen, Huang, Lu, and Peng 2002).

2.6.2 Plateau Wetland Vertebrate Species

Wetland-dwelling vertebrate species play an important role in wetland ecosystems and are considered to include any vertebrate that spends all or part of the year residing at a wetland. On the Qinghai-Tibet Plateau, alpine wetlands provide habitat for many rare vertebrates, including numerous species of endangered birds, mammals, fish, and amphibians. In Qinghai Province there are 73 bird species, 55 fish species, 14 mammal species, and 9 amphibian species considered to be resident in Qinghai's wetlands (Chen, Huang, Lu, and Peng 2002).

Alpine wet meadows provide the necessary conditions for migratory waterfowl to nest, and thus form critical habitat for a variety of water birds on the Qinghai-Tibet Plateau. In the alpine wetlands of the Yangtze Source Region alone there are 29 species of water birds that nest in summer, including the great-crested grebe (*Podiceps cristatus*), grey heron (*Ardea cinerea rectirostris*), bar-headed goose (*Anser indicus*), and ruddy shelduck (*Tadorna ferruginea*), which are all locally common (Photos 2.11, 2.12, and 2.13) (Chen, Huang, Lu, and Peng 2002). The black-necked crane (*Grus nigricollis*) is one of the rarest birds that nests in the Yangtze Source Region, and an important portion of this crane's summer nesting grounds in the region is protected in Qinghai's Longbaotan National Nature Reserve (Photo 2.14). In addition, the vast areas of lakes and marshes in the Yel-

Photo 2.11. Ruddy shelducks. Photo by Yifei Zhang.

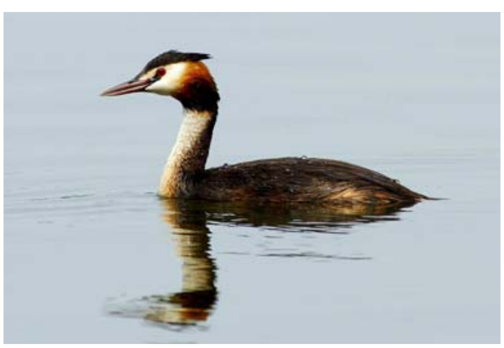

Photo 2.12. Great-crested grebe. Photo by Yifei Zhang.

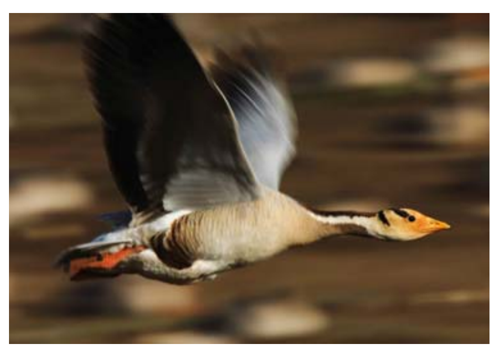

Photo 2.13. Bar-headed goose. Photo by Yifei Zhang.

low River Source Region also provide excellent summer nesting grounds for waterfowl such as the black-necked crane, ruddy shelduck, great cormorant (*Phalacrocorax carbo*), and Pallas's Gull (*Larus ichthyaetus*), including at Gyaring Co, Ngoring Co, and Xingxiu Lakes (Photo 2.24) (Chen, Huang, Lu, and Peng 2002).

There are a number of wild ungulates that commonly reside in or near the alpine wet meadows of the Yangtze and Yellow River Source Regions, including the wild yak (*Bos mutus*), Tibetan antelope (*Pantholops hodgsonii*), and Tibetan wild ass (*Equus kiang*), where these animals both drink and graze (Photos 2.15, 2.16, and 2.17). Up to now, 19 species of fish have been identified in the source region of the Yangtze River, including such high altitude, cold water fish as the Cyprinidae *Ptychobarbus kaznakovi* and *Schizopygopsis microcephalus*, and the Balitoridae *Triplophysa stenura* (Chen, Huang, Lu, and Peng 2002).

Photo 2.14. Black-necked cranes. Photo by Yifei Zhang.

Photo 2.15. Wild yak bull. Photo by Dawa Tsering.

Photo 2.16. Tibetan antelope. File photo.

Photo 2.17. Tibetan wild ass. Photo by Dawa Tsering.

2.7 The Features and Status of Characteristic Wetlands of the Qinghai-Tibet Plateau

2.7.1 Wet Meadow Type Wetlands: The Zoige Wetlands

2.7.1.1 Location and Features

The Zoige Basin is a fault block basin located in the northeast of the Qinghai-Tibet Plateau where the boundaries of Sichuan, Qinghai, and Gansu Provinces meet (Photo 2.10). The basin sits between latitudes of approximately 32°20'–34°00' N and longitudes of 101°36'–103°30' E and has a total area of about 70,800 km^2, with the basin floor being typically 3600-3800 m in elevation (Wang, Shi, and Shen 1995). The basin represents a zone of relative subsidence within plateau terrain that was sharply uplifted during the late Cenozoic, and sediments in the basin are typically 200-300 m thick with basal layers that date to the Neogene (Lehmkuhl and Spönemann 1994). The geomorphology of the Zoige Basin includes low mountain ranges, hills, river valleys, river terraces, ancient glaciated valleys, and extensive bogs and lakes.

The climate of the Zoige Basin is typical of cold-wet areas of the plateau, with the basin having higher precipitation and humidity than elsewhere on the plateau as well as an exceptionally long frost period. Annual mean temperatures in the basin range from 0.6-1.2ºC, with the average temperature being -10.7ºC in January and +10.9ºC in July (Liu and Zhang 2001). Annual mean precipitation in the Zoige Basin ranges from 660-750 mm, depending on location, with a distinct rainy season occurring from May to October that accounts for 90 percent of total annual precipitation (Liu and Zhang 2001). The Yellow River flows through the western part of the Zoige Basin, and most of the basin's rivers drain into it, including two of the upper Yellow River's largest tributaries, the Hei He and Bai He Rivers. The channels of these two tributaries have very low slopes, which has caused both rivers to develop intricate systems of meandering river bends. Because of the Zoige Basin's poor drainage and relatively high annual precipitation, the basin is covered year-round by vast areas of standing water, which includes a number of significant lakes, notably Haqiu, Co Lajian, and Xing Co Lakes. Sites with perennial, seasonal, and storm event-dependent groundwater seepage can be found throughout the basin.

Soils of the Zoige Basin are highly developed and include alpine meadow, alpine wet meadow, and alpine turf type soils, the last two of which are typical of the basin's wide valley bottoms and lakeside bogs. Zoige soils are generally neutral or slightly alkaline, with pH values ranging from about 7.0-8.0, and are underlain by a deep gley soil horizon (Liu and Zhang 2001). Parent materials for soil formation are primarily fine sediments and sub-clays, thus the hydrological and soil conditions in the Zoige Basin are highly favorable to the formation of wet meadow type wetlands. Peat in the Zoige Basin occurs in relatively thick layers which range from 3–10 m in thickness, and the degree of decomposition of this peat is low, with its organic content being generally greater than 50 percent (Liu and Zhang 2001).

Plant communities in the Zoige Basin consist primarily of alpine meadows and alpine wet meadows. While alpine meadows are found on hills, mountain valleys, river terraces, and other elevated areas, alpine wet meadows are widespread along the middle and lower reaches of the Bai He and Hei He Rivers, including along the perimeters of oxbow lakes, bogs, and marshes; in large seep areas at the foot of hills and mountains; and in other poorly drained areas (Photo 2.18) (Wang, Wang, Zhang and Lu 2001). In addition, the Zoige Basin also has extensive shrub cover that is generally found on shady mountain slopes and in narrow stream gulches as well as at the foot of the mountain ranges which ring the basin (Wang, Wang, Zhang and Lu 2001).

Photo 2.18. Zoige Marshes, Zoige County, Sichuan Province. Photo by David Blank, GEF Project CPR/98/G32, Wetlands Biodiversity Conservation and Sustainable Use in China.

There are 1208 species of higher plants in the meadows of the Zoige Basin, which represent 131 families and 573 genera (Xiang, Guo, Wu, and Sun 2009; He and Zhao 1999). Of these, about 200 species are wetland plant species found in the basin's vast wet meadows and marshes, many of which are considered to be rare or endangered (He and Zhao 1999). *Kobresia tibetica* and *Carex muliensis* are considered to be the most representative plants of the region's wetlands, while rare and endangered plants in the Zoige Basin include *Potamogeton fiuformis* var. *applanatus*, *P. heterophyllus*, *P. pectinatus*, and *Isoetes hypsophila*. There are also over 100 species of medicinal plants found in the Zoige Basin, including fritillary (*Fritillaria cirrhosa*, Chinese: beimu 贝母), rhubarb (*Rheum rhabarbarum*, Chinese: boye dahuang 波叶大黄), caterpillar fungus (*Cordyceps sinensis*, Chinese: dongchong xiacao, abbreviated as "chongcao," 冬虫夏草, Tibetan: yartsa gunbu), angelica root (*Angelica pubescens*, Chinese: duhuo 独活), wild celery (*Vallisneria spiralis*, Chinese: kucao 苦草), membranous milk-vetch root (*Astragalus membranaceus*, Chinese: huangqi 黄芪), Chinese goldthread (*Coptis chinensis*, Chinese: huanglian 黄连), and notopterygium root (*Notopterygium incisum*, Chinese: qianghuo 羌活), which are all used in traditional Chinese medicine (Liu and Zhang 2001). Grasses in the basin sprout early, making the Zoige region's pastures ideal for grazing livestock in late winter and early spring, and with their high quality and yield, the pastures of the Zoige Basin are amongst the five most important livestock production areas in China (He and Zhao 1999).

Vertebrate life in the Zoige Basin is also rich, with there being 251 vertebrate species in the basin representing 29 orders and 65 families (Liu and Zhang 2001). Of these, there are 162 species of birds from 15 orders and 34 families, 62 species of mammals from 8 orders and 21 families, 19 species of fish from 2 orders and 4 families, 4 species of amphibians from 2 orders and 3 families, and 4 species

Photo 2.19. Tibetan gazelle. Photo by Dawa Tsering.

of reptiles from 2 orders and 3 families (Liu and Zhang 2001). Notable bird species in the Zoige Basin include the endangered black-necked crane, about 710 of which summer in the basin, the white stork (*Ciconia ciconia*), white-bellied sea eagle (*Haliaetus leucoryphus*), white-tailed eagle (*Haliaeetus albicilla*), and cinereous vulture (*Aegypius monachus*) (McNamee 2002). Notable mammals in the Zoige Basin include Tibetan blue sheep (*Pseudois nayaur* Hodgson), Macneill's red deer (*Cervus elaphus macneilli* Lydekker), sika deer (*Cervus nippon*), white-lipped deer (*Cervus albirostris* Przewalski), Tibetan gazelle (*Procapra picticaudata* Hodgson), and common otter (*Lutra lutra* Linnaeus) (Photo 2.19)(McNamee 2002).

2.7.1.2 Ecological Threats: Pasture Degradation and Desertification

In spite of the South Asian monsoon being the main source of precipitation on the plateau region of western Sichuan, total precipitation in the Zoige Basin has decreased in recent years due to the general climatic trend in the region of warming and increasing aridity, which is believed to be the result of global climate change (Liu and Zhang, 2001). This warming and drying trend combined with the basin's high degree of human disturbance is having a severe impact on Zoige's fragile wetlands and meadows, which are slow to recover from damage due to the region's high altitude and cool climate. In recent years these impacts have included the rapid conversion of Zoige's marshes and wet meadows to dry meadows and even to barren lands free of vegetation (Liu and Zhang, 2001).

Pasture degradation resulting from overgrazing in the Zoige Basin is an enormous problem, as both dry pastures and wetlands are indiscriminately used for grazing large numbers of livestock, a direct result of initiatives to increase livestock production to unsustainable levels in the basin (Liu and Zhang 2001). In the process, not only formerly productive pastures have been lost, but wetlands used to graze livestock have also been damaged, reducing the diversity of wetland plants and causing a decline in the ecological functionality of wetlands in the basin. In the long term, livestock productivity in the Zoige Basin will also decline as a result of this damage.

In spite of its extensive wetlands areas, parts of the Zoige Basin are now suffering from desertification as a direct result of overgrazing of livestock, and a total of 4091 ha of grasslands in the basin have already been converted to desert, a figure that was increasing by about 2.3 percent annually as of 2001 (Liu and Zhang 2001). While desertification in the Zoige Basin initially began on low mountains, hills, and the relatively drier edges of valleys, some sand dunes have now even spread into marsh areas. The main source of sand for dune formation is from

hillslopes with thin topsoils, the alluvial fans that ring the Zoige Basin, and from the bar deposits found in abandoned channels of rivers that have shifted course in the basin. Sparse hillslope meadows hold underlying sands in place but are quickly denuded by the large numbers of livestock grazing in the Zoige Basin, leading to the wind-driven movement of sand and formation of dunes, which in turn bury and destroy more pasture areas leading to the formation of even more sand dunes (Photo 2.20). Once formed, meadow plants are slow to colonize these sandy areas, particularly where the water table is far below the soil surface, and vegetation on these sand patches, if any, generally consists of only sparsely growing grasses.

Photo 2.20. Sand Dunes, Zoige Basin, Zoige County, Sichuan. Photo by Peter McNamee, GEF Project CPR/98/G32, Wetlands Biodiversity Conservation and Sustainable Use in China.

Thus, the impacts of pasture degradation and desertification in the Zoige Basin since the 1960s have included a 20 percent decline in grassland productivity, a 20 percent decline in usable pasture area in the basin, a 10 to 20 percent increase in unpalatable and ruderal plant species, and a decrease in gramineous grass composition of the basin's pastures from 30 percent of plant cover to just 16 percent (Liu and Zhang 2001). Furthermore, *Stellera chamaejasme*, a plant which is poisonous to livestock, is now spreading throughout the Zoige Basin and in some areas is even becoming a primary pasture species (Photo 2.21) (Liu and Zhang 2001).

Photo 2.21. *Stellera chamaejasme*, a common invasive plant species in the Zoige Basin which is poisonous to livestock. Photo by David Boufford, Biodiversity of the Hengduan Mountains Project, Harvard University.

2.7.1.3 Ecological Threats: Falling Groundwater Levels

Falling groundwater levels, the disappearance of perched aquifers, and soil salinization have all become large problems in the Zoige Basin in recent years and are the result of a variety of factors, including draining of wetlands to increase total area of pastures, increasing use of groundwater by local residents following pasture privatization, and the general regional climatic trend towards warming and increasing aridity (He and Zhao 1999). As a consequence, groundwater levels in the basin have fallen in some areas by up to ten meters, while reduced flows of surface and groundwater at Zoige permit salts to accumulate in topsoils (Yan and Wu 2005, He and Zhao 1999). In addition to contributing to the drying up of Zoige's wet-

lands, other consequences of falling groundwater tables and subsequent soil salinization in the basin have included declines in pasture productivity and forage nutrition levels, which in turn have diminished the basin's ability to support both livestock and high levels of biodiversity (Liu and Zhang 2001).

2.7.1.4 Ecological Threats: Changes in Wetland Soil Properties

Both climate change and human activities have adversely affected the chemical and physical properties of soils in the Zoige Wetlands, which are largely a function of climatic conditions, water quality, peat type, degree of soil hydration, degree of organic decomposition, calcium carbonate content, and other mineral content (He and Zhao 1999). According to a nutrient analysis of marsh soils in the Zoige Basin, the content of soluble nitrogen, phosphorus, and potassium have recently increased with respect to older marsh soils in the basin (He and Zhao 1999). In marsh soils, nitrogen, phosphorus, and potassium exist in an organic, insoluble form (He and Zhao 1999). For example, insoluble nitrogen exists in proteins or trapped in humic acid where it is a potential nutrient, but before it can be absorbed by plants to fuel growth it must be converted to a soluble form, as is also the case for phosphorus and potassium. When moisture content in marsh soils decreases, soil aeration increases, ground temperatures rise, the activity level of aerobic soil microorganisms increases, and the decomposition of organic matter accelerates, transforming formerly insoluble nitrogen, phosphorus, and potassium into soluble nutrients that wetland vegetation can utilize for growth. Thus the recent trend toward climatic warming and drying at Zoige, in combination with the effects of human activities such as draining of wetlands to increase the area of pastures, has increased the activity level of aerobic soil microorganisms and consequently increased the available supply of soluble plant nutrients in Zoige's marsh soils (He and Zhao 1999). However, the benefits of improved soil nutrient supplies in marsh soils are often negated by the over-draining of wetlands by humans and the overgrazing of wetland plant resources by their livestock, which can eventually lead to an overall degradation of the natural chemical and physical properties of wetland soils. If left unchecked, overexploitation of Zoige's wetland ecosystems by humans may ultimately lead to a decrease in the level of plant nutrients in wetland soils and to a sharp decline in wetland plant and animal productivity as well as an overall decline in the biodiversity of the Zoige Basin (He and Zhao 1999).

2.7.1.5 Ecological Threats: Peat Mining

Another looming threat to the ecology of the Zoige Basin's wetlands is peat mining, which threatens the wholesale destruction of large areas of Zoige's wetland ecosystems. Total peat reserves in the Zoige Basin are estimated to be 1.9 billon tons (dry weight), which account for 41 percent of China's known peat resources (He and Zhao 1999). With an average heat capacity of about 13,820 J/kg, Zoige peat is considered to be of high quality, and consequently there is great domestic and international interest in exploiting Zoige's peat resources for power generation (He, Zhao, and Zhao 2000a, 2000b). To date, 138 large- and 82 medium-sized peat deposits have already been explored, and a 1500 kW peat-pithead demonstration power plant has been built in Zoige County (He, Zhao, and Zhao 2000a, 2000b).

Zoige peat is also used as a raw material in fertilizer production, thus it appears that large-scale extraction of peat resources in the Zoige Basin will eventually occur regardless of the impact of these activities on the basin's wetlands.

2.7.2 River Source Area Type Wetlands: The Three Rivers Source Region

2.7.2.1 Location and Features

The source areas of the Yangtze, Yellow, and Mekong Rivers are all located in adjacent basins on the Chang Tang grasslands of southern Qinghai Province, and collectively the upper basins of these rivers are known as the "Three Rivers Source Region." The Three Rivers Source Region has an average elevation of about 4000 m and covers a total area of 316,000 km^2, or about 44 percent of the total area of Qinghai Province, which includes most of Yushu and Golog Tibetan Autonomous Prefectures; Xinghai and Tongde Counties in Hainan Tibetan Autonomous Prefecture; Zekog and Henan Counties in Huangnan Tibetan Autonomous Prefecture; and most of the Tanggula District in the southwest corner of Qinghai, which is jointly administered by the city of Golmud in Qinghai and Amdo County in the TAR's Nagchu Prefecture (Liu, Zhang, Zhang, Zhou, and Duo 2005). Wetlands in the Three Rivers Source Region have an area of about 10,000 km^2, which includes two large lakes, Gyaring Co and Ngoring Co, that play an important role in regulating the flow of the upper Yellow River (Photo 2.24). In addition, there are more than 80 rivers in the Three Rivers Source Region with drainage areas greater than 500 km^2, and surface flow originating in this region of Qinghai accounts for about half of the Yellow River's total annual flow volume as well as significant percentages of the total annual flow of both the Yangtze and Mekong Rivers (Liu, Zhang, Zhang, Zhou, and Duo 2005; Zhu, Giordano, Cai, and Molden 2004). Therefore, maintaining the ecological integrity of wetlands in the Three Rivers Source Region is critical for conservation of some of China's most important sources of water.

Although covering a vast area, the Three Rivers Source Region is only sparsely populated, and to date it remains comprised almost entirely of one of the world's last largely intact grassland ecosystems. There are 1728 species of higher plants recorded in the region that represent 406 genera and 89 families, including 1680 species of angiosperms, 20 species of gymnosperms, and 28 species of ferns. Grassland and wetland plant species of note include *Stipa purpurea*, *S. bungeana*, *S. krylovii*, *S. breviflora*, *Kobresia schoenoides*, *K. pygmaea*, *K. humilis*, *K. capillifolia*, *Carex moorcroftii*, *Artemisia frigida*, *Achnatherum splendens*, *Littledalea racemosa*, *Potamogeton pectinatus*, *P. pusillus*, and *Eleocharis* spp. Notable tree and shrub species occurring in the Three Rivers Source Region include *Picea crassifolia*, *P. likiangensis*, *Sabina przewalskii*, *S. tibetica*, *Betula platyphylla*, *B. albosinensis*, *Populus davidiana*, *Rhododendron capitatum*, *Rh. thymifolium*, *Salix oritrepha*, *Potentilla fruticosa*, *Caragana jubata*, *Sibiraea angustata*, *Spiraea alpina*, *Hippophae tibetica*, *H. rhamnoides*, *Berberis* spp., and *Myricaria* spp. As elsewhere on the Qinghai-Tibet Plateau, many species of wild plants found in the Three Rivers

Photo 2.22. Tibetan argali. Photo by Dawa (Tsonyi).

Photo 2.23. Tibetan brown bear. File photo: Nagchu Prefecture Forestry Bureau, TAR.

Source Region are important for use in Chinese and Tibetan traditional medicine (summarized from Chen, Lu, Peng, and Zhao 2003).

With respect to wildlife, there are 360 species of wild animals known to inhabit the Three Rivers Source Region, which are comprised of 213 species of birds, 96 mammal species, 36 fish species, 8 amphibian species, and 7 reptile species (Chen, Lu, Peng, and Zhao 2003). These include such rare and endangered species as the Tibetan antelope, Tibetan wild ass, Tibetan argali (*Ovis ammon hodgsoni*), wild yak, white-lipped deer, musk deer (*Moschus* spp.), snow leopard (*Uncia uncia*), Tibetan brown bear (*Ursus arctos pruinosus*), Eurasian lynx (*Felis lynx*), black-necked crane, golden eag1e (*Aquila chrysaetos*), saker falcon (*Falco cherrug*) and Tibetan snowcock (*Tetraogallus tibetanus*) (Photos 2.22 and 2.23) (Schaller, 1998).

2.7.2.2 Ecological Threats: Decline of Surface Water Resources

One ecological threat to the Three Rivers Source Region has been the steady decline of the region's surface water resources. For example, between 1952 and 1978, the water surface levels of the adjacent Gyaring Co and Ngoring Co Lakes on the upper Yellow River fell by 60 cm, or 2.3 cm/year, while between the 1970s and 1999, the surface elevation of Ngoring Co fell a further 433 cm, from 4272.12 m to 4267.79 m (Photo 2.24) (Jing and You 1982; Qi, Luo, and Xiao 2005). In the Yangtze River Source Region, the water level and surface area of many lakes have declined dramatically, such as at Qoima Co Lake, where analysis of satellite images shows that the total surface area of the lake decreased by nearly half between the 1970s and 1990s (Sun, Deng, and Shao 1995). With respect to rivers, the Yellow River has completely ceased to flow in its source region on three separate occasions since measurement of flow in the region began in the 1950s, in the winters of 1961, 1981, and 1998 (Photo 2.25) (Yang and

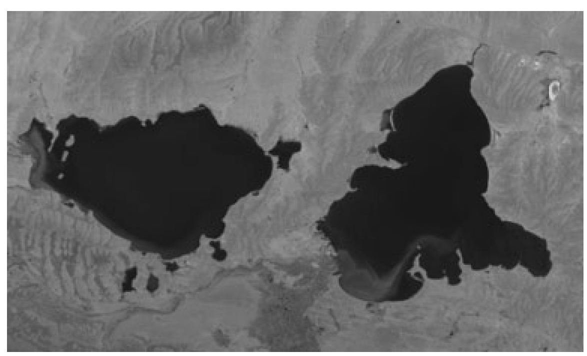

Photo 2.24. Gyaring and Ngoring Co Lakes, Yellow River Source Region, Qinghai. NASA Landsat image.

Zhang, 1999). In terms of wetlands, analysis of satellite images shows that at the beginning of the 1980s, wet meadows and marshes in the Yellow River Source Region covered a total area of 3895 km^2. However, by the 1990s, the total area of these wetlands had decreased to 3247 km^2, a total loss of 648 km^2, or an annual average loss of 58 km^2 of wetlands (Chen, Huang, Lu, and Peng 2002). In the Yangtze River Source Region, many wet meadows at the base of mountains have simply dried up and been invaded by various xerophilic plants that are more typical of arid areas than wetlands (Wang 1998). The drying up of lakes, rivers, and other wetlands in the Three Rivers Source Region are all believed to be phenomena resulting from global climate change, the impacts of which have included decreased precipitation; increased evaporation; the meltoff of river source glaciers; and the degradation of permafrost that underlies many river source area type wetlands, which ordinarily impedes the deep percolation of surface water.

Photo 2.25. Yellow River, Madoi County, Qinghai. Photo by Dawa Tsering.

2.7.2.3 Ecological Threats: Pasture Degradation and Desertification

At the same time as the Three River Source Region's surface waters dry up, the region's grasslands are also becoming severely degraded due to a combination of chronic overgrazing and climate change (Liu, Zhang, Zhang, Zhou and Duo 2005). As of 1998, there were 25,000 km^2 of degraded pasture in the Three Rivers Source Region. Of these degraded pastures, about 2,500 km^2 had lost all their vegetation and been converted to bare sand patches that are known locally as "black beach" areas (Liu, Zhang, Zhang, Zhou, and Duo, 2005). One effect of the recent degradation of vast areas of pastures in the Three Rivers Source Region has been to allow black-lipped pika (*Ochotona curzoniae*) populations in the region to flourish. Research has shown that as of 2005 there were an average of 120 pikas and 1624 pika burrows per hectare in the region, with these pikas consuming 4.7 million tonnes of forage annually, or enough forage to feed 2,860,000 sheep for one year (Photo 2.26) (Liu, Zhang, Zhang, Zhou, and Duo, 2005). Many livestock herders feel that these pikas are the cause of pasture degradation and desertification in the Three Rivers Source Region, and extensive, highly unsuccessful, poisoning campaigns to eliminate these animals have been carried out. However, some grassland scientists feel that the exploding pika populations in the Three Rivers Source Region are merely a symptom, not a cause, of pasture degradation, which is generally the result of grazing livestock in numbers far exceeding the carrying capacity of the region's grasslands (Smith and Foggin, 1999).

Photo 2.26. Black-lipped pika. Photo by John D. Farrington.

Large-scale desertification of former pasturelands is an enormous problem in Gansu Province's Machu County, which is located on the upper Yellow River and includes the westernmost section of the Zoige Wetlands. According to historical records, in the 1950s there were no sand dunes or desertified lands in Machu County, and these features of grassland degradation only began to appear as limited patches and small dunes in the 1960s. However, between 1980 and 1985 it is recorded that 1440 ha of grasslands were desertified, an average rate of over 200 ha/year during this period. While earlier only scattered patches of land had been desertified, about this time, large shifting sand dunes began to appear at an alarming rate. A 1994 investigation found that 4798 ha of former pasture had been converted to desert in Machu, of which 1744 ha consisted of shifting sand dunes, while the remaining 3054 ha consisted of stable sands. As of 1999, the total area of desertified land in Machu County had increased by a further 1282 ha, of which 276 ha consisted of shifting dunes, while the remaining 1006 ha consisted of stable sands. In addition to the loss of large areas of grasslands to desertification in Machu County, the number of primary grassland plant species in the county has declined precipitiously, with nine of an original thirty primary grassland plant species having virtually disappeared in Machu between 1981 and 1997 (summarized from Zhang and Ma 2001).

The primary cause of desertification in Machu County is the chronic overstocking of livestock on what already were sandy soils and the subsequent overgrazing that ensued. However, this situation has been greatly exacerbated by the increasing temperatures and aridity of the region brought on by global climate change in recent decades. Between 1950 and 1998, livestock numbers in Machu County nearly tripled, with there having been about 240,000 head of livestock in Machu County during the 1950s, which increased to 330,000 during the 1960s, 450,000 in the 1970s, 640,000 in the 1980s, finally reaching 701,530 head in 1998 (Zhang and Ma 2001). By one estimate, livestock numbers already exceeded the carrying capacity of Machu's pastures by 350,000 sheep units in 1989, a figure which had grown to 400,000 by 1998, leading to a situation of severe ecological degradation in the county, as evidenced by the prolific increase in sand dunes in Machu in the late 20th Century (Zhang and Ma 2001). As more pastures are destroyed by the excessive numbers of livestock in Machu County or are simply buried under shifting

sands driven by the region's strong winds, there appears to be no end in sight for the problem of desertification in Machu.

2.7.3 Lake Basin Type Wetlands: Qinghai Lake

2.7.3.1 Location and Features

Located between latitudes of 36°15'–38°20' N and longitudes of 97°50'–101°31' E, the Qinghai Lake basin has a length of 165 km from east to west, a width of 109 km from north to south, and a total area of 29,660 km^2, or about 4.1 percent of the territory of Qinghai Province (Photo 2.7) (Wang and Sun 1999). The lake itself lies south of the Qilian Range, occupying a fault block basin formed by Datong Mountain to the north, Qinghai Nanshan Mountain to the south, Riyue Mountain to the east, and Amuniniku Mountain to the west. Qinghai Lake is a closed-basin saline lake with a lake surface elevation of about 3195 m and a surface area of about 4400 km^2, making it the largest lake on the Qinghai-Tibet Plateau (An, Ai, Song, and Colman 2006). There are a variety of wetland types in the Qinghai Lake basin, including wet meadow, river source area, and lake type wetlands, which are all dominated by extremely sensitive, low productivity, high altitude ecosystems that are slow to repair themselves when damaged. The climate in the Qinghai Lake basin is temperate and cool with a large diurnal temperature variation. Due to a lake effect, precipitation in the lake basin is higher than elsewhere in the region, providing conditions that are advantageous for pasture growth and soil formation. At present, grasslands cover 18,690 km^2 in the Qinghai Lake Basin, or about 63 percent of the total area of the basin, and there are broad fertile pastures along the lake's shores which provide excellent winter and spring forage (Li, Ma, Xu, Wang, and Zhang 2009). Unfortunately, however, much of these pasturelands have been fenced off and/or converted to ploughland, severely fragmenting wildlife habitat around the lake in the process.

In terms of terrestrial vegetation, the area immediately around the shore of Qinghai Lake is comprised of dry steppe grasslands, with grass species in these areas being dominated by the genera *Stipa*, *Agropyron*, and *Achnantherum*. However, in desertified areas of the lakeshore region, particularly in the shifting dune fields along the eastern shore of the lake, vegetation is extremely sparse, and includes plants of the genera *Artemisia*, *Orinus*, and *Triglochin*. In areas of the lakeshore with highly saline soils, such as on the western shore of the lake, vegetation is also sparse, and dominated by plants of the genera *Puccinellia* and *Salsola*, with some species of the genera *Elymus*, *Blysmus*, and *Iris* occurring in these areas. At eleva-tions above 3300 m on hillslopes surrounding the lake, thicker, moister soils permit a transition from steppe to meadow type grasslands where vegetation is dominated by the genera *Kobresia*, *Stipa*, and *Potentilla*. On the steeper, shadier, north-facing slopes, some shrublands occur (summarized from Tolvanen 2001). In total, there are over 300 plant species in the Qinghai Lake area, which include species of the genera *Poa*, *Festuca*, *Stipa*, *Allium*, *Polygonum*,

Stellaria, *Aconitum*, *Delphinum*, *Ranuculus*, *Draba*, *Corydalis*, *Sedum*, *Saxifraga*, *Potentilla*, *Oxytropis*, *Astragalus*, *Geranium*, *Pleurospermum*, *Gentiana*, *Pleurogyne*, *Pedicularis*, *Aster*, *Leontopodi-um*, *Anaphalis*, *Artemisia* and *Saussurea* (Hao 1938, cited in Tolvanen 2001). Aquatic vegetation in Qinghai Lake includes species of *Potamogeton* and *Zannichellia qinghaiensis*, while other macrophytes occur sparsely in near-shore areas (Chen 1987, cited in Walker and Yang 1999). In terms of phytoplankton, there are 66 genera recorded from the lake, including 23 *Bacillariophyta*, 26 *Chlorophyta*, and 12 *Cyanophyta*, and dense growths of the chlorophyte *Cladophora* prevent trawling activities in some areas (Chen 1987, cited in Walker and Yang 1999).

Photo 2.27. Great cormorant colony, Qinghai Lake, Qinghai Province. Photo by Dawa Tsering.

In spite of severe degradation of the natural habitat in the Qinghai Lake basin over the last five decades, there remain 164 species of birds, 36 species of wild mammals, 6 species of fish, 3 species of reptiles, and 2 species of amphibians that reside in the lake basin (Wang and Sun 1999). Species of note include the world's last remaining 400 Przewalski's gazelle (*Procapra przewalskii*), the black-necked crane, and other rare species of waterfowl, many of which nest at the Bird Island Ramsar Site located at the western end of the lake (Photo 2.27). Throughout the last four decades of the 20th Century, the "naked" or "scale-less" carp (*Gymnocypris przewalskii*) was the basis of a significant commercial fishery on the lake. The zooplankton of Qinghai Lake consists of 57 taxa, including 9 Protozoa (mainly *Carchesium*), 21 Rotifera (mainly *Hexarthra fennica*), 17 Cladocera (mainly *Moina rectirostris*) and 10 Copepoda (mainly *Arctodiaptomus salinus*) (Chen 1987, cited in Walker and Yang 1999). The benthic fauna of the lake includes 43 taxa, including an amphipod (*Gammarus* sp.), 34 insects, 5 molluscs, and 3 oligochaetes, but chironomids (especially *Tendipes reductus* complex) comprise 87 percent of the lake's benthic biomass (Chen 1987, cited in Walker and Yang 1999).

2.7.3.2 Ecological Threats: Falling Lake Level

Analysis of Qinghai Lake's ancient high water line indicates that at its peak size during the late Pleistocene, the lake had a surface area of 8200 km^2, or nearly twice the lake's current surface area (Wang, Wang, Wu, and Li 1991). In terms of water surface elevation, in 1908 Qinghai Lake's water surface level stood at 3205 m but by 1975 had dropped to 3196.57 m, an average annual fall of about 12.7 cm/year. This resulted in an average annual decrease in the lake's surface area of about 8.4 km^2/year (Wang and Sun 1999). By 1991 the lake's water surface elevation had fallen a further 3 m to 3193.59 m, with the maximum depth of the lake having decreased from about 37.5 m at the beginning of the 20th Century to just 25 m in the late 1990s (Wang and Sun 1999). The dramatic decline in the depth and area of

Qinghai Lake in the 20th Century is generally attributed to increasing temperatures and aridity in the region resulting from global climate change, which has led to a decrease in the amount of precipitation and runoff that feed the lake while at the same time increasing the rate of evaporation from the lake's surface (Wang and Sun 1999; Sun, Li, Liu Xu, and Zhang 2008). Of the over 108 rivers that flowed into Qinghai Lake in the 1950s, which formerly accounted for about 80 percent of the total volume of water entering the lake each year, only about 40 persisted in reaching the lake as of 2005 (Sun 2005). Consequently, the total volume of river flow entering the lake decreased by roughly 60 percent between 1985 and 2005 (Sun 2005). While the disappearance of these streams is believed to be primarily due to climate change, Walker and Yang have noted that the diversion of water for irrigation in the Qinghai Lake basin has also contributed to falling lake levels and increasing salinity of the lake in the second half of the 20th Century (Walker and Yang 1999).

In 2006 An, et al. reported the water surface elevation of Qinghai Lake to be 3194 m, which showed little change from the 1991 level of 3193.59 m (An, Ai, Song, and Colman 2006). However, in June 2008, the People's Daily reported that Qinghai Lake had reached its lowest level in 40 years in 2004 with a surface area of just 4186 km^2, but that the lake had actually risen in each of the three following years, increasing in size by 78 km^2 in 2005, by 88 km^2 in 2006, and by 137 km^2 in 2007 (People's Daily, 2008). In February 2009, the China Meteorological Administration online news reported that the lake's water level rose for a fourth straight year in 2008, with a total increase in lake level of 50 cm between 2005 and 2008 (Photo 2.28) (Dai 2009). The reason for this sudden, dramatic rise in lake level is attributed to increasing precipitation in the lake basin, which from 2004-2008 averaged 431.3 mm/year, a 17 percent increase in annual mean precipitation over the arid period from 1991-2003 (Dai 2009). Furthermore, the recent increase in precipitation at Qinghai Lake has naturally been accompanied by an increasing duration of cloud cover that has contributed towards decreasing the rate of evaporation from the lake's surface (Dai 2009). While it can not be predicted how long Qinghai Lake will continue to rise, the rising lake level is mitigating the long-term problem of desertification of lakeshore lands, discussed in the following section.

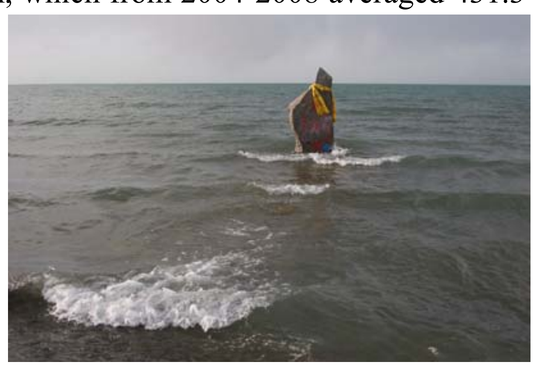

Photo 2.28. Qinghai Lake marker stone erected at the water's edge in the spring of 2007, which was under 30 cm of water when photographed in September 2009 due to increased rainfall in the lake basin. Photo by Dawa Tsering.

2.7.3.3 Ecological Threats: Desertification of Lakeshore Areas

After the slow drying up of Qinghai Lake and its surrounding wetlands and streams, the second largest ecological threat to the lake basin is that of widespread desertification (Photo 2.29). Lakeshore areas are particularly affected, since as

Table 2.2 Remote sensing assessment of sandy lands in the Qinghai Lake basin, 1977-2004.

Year	Area of Sandy Lands (km^2)	Average Rate of Increase of Sandy Lands (km^2/year)
1977	587.4	-
1987	660.7	7.3
2000	697.6	2.8
2004	805.8	27.1

Source: Sun, Li, Liu, Xu, and Zhang, 2008.

Qinghai Lake's surface area shrank in the 20th Century, newly exposed land consisted of salty, wind-driven sands that were quick to form dunes, a problem that is particularly acute along the downwind eastern shore of the lake. Research has shown that the percentage of desertified land along the periphery of Qinghai Lake grew from 51 percent of lake-shore lands in the 1950s, to 67 percent of lakeshore lands in the 1980s (Wang and Sun 1999). In total, between 1960 and 1988, the area of desertified lakeshore lands at Qinghai Lake grew by 306.6 km^2, an average rate of increase of nearly 11 km^2/year, which corresponds closely to the rate at which new land was exposed by falling lake levels during this period (Wang and Sun, 1999). As of 2003, it was reported that the total area of desertified lake periphery lands was 1695 km^2 (Zhang, Wu, Lu, Zhao, and Chen 2003). In another study, a remote sensing analysis of "sandy lands" detectable on satellite images of the basin found that in 1977, the total area of sandy lands in the Qinghai Lake basin was 587.4 km^2, which had grown to 660.7 km^2 by 1987, 697.6 km^2 by 2000, and 805.8 km^2, or 2.7 percent of the entire basin, by 2004. This represents an average annual growth rate of sandy lands in the basin of 7.3 km^2/year from 1977-1987, and an alarming rate of growth of these lands of 27 km^2/year from 2000-2004 (Table 2.2) (Sun, Li, Liu, Xu, and Zhang 2008). Furthermore, it has been estimated that 8.87 million tons of aeolian sands enter the lake each year, further decreasing the lake's total water volume (Zhang, Wu, Lu, Zhao, and Chen 2003). Although the total area of desertified lands along the lakeshore is now decreasing as Qinghai Lake rises, the area of land in the lake basin desertified by overgrazing, a problem which is exacerbated by climate change, may continue to grow (see section 2.7.3.5, below).

Photo 2.29. Sand dunes, Haiyan Bay area, northeastern Qinghai Lake, Qinghai Province. Photo by Dawa Tsering.

2.7.3.4 Ecological Threats: Conversion of Grasslands to Croplands and Desertification

In addition to the climate change driven decline in lake surface levels, desertification in the Qinghai Lake basin is also a direct result of poor land-use practices amongst the over 97,000 human inhabitants of the lake basin, most of

whom earn their livings by either growing crops, primarily barley and rape seed, or by herding sheep, goats, yaks, and other livestock (Photo 2.30) (Yan and Jia 2003,cited in Li, Xu, Sun, Zhang, and Yang 2007; Walker and Yang, 1999). In the 1950s, extensive ploughing of pastures surrounding the lake began in order to increase agricultural production, and by the end of the 20th Century a total of 44,900 ha of grasslands in the lake basin had been ploughed and converted to cropland (Wang and Sun 1999). Unfortunately, the steppe grasslands surrounding Qinghai Lake only have a very thin layer of topsoil beneath them, which after ploughing remains bare and exposed to strong winds for half the year from the time of harvest in the fall until being planted again in spring. As a result, this limited topsoil is quickly blown away causing soil fertility to decline. Consequently, within a few years after ploughing these new farmlands are no longer capable of supporting crops and are abandoned, and as of 2005, there were only about 20,000 ha of land actively being farmed in the Qinghai Lake basin (Li, Xu, Sun, Zhang, and Yang 2007). Once abandoned, however, these former croplands are slow to be recolonized by grasses in the arid environment and generally remain bare and a source of sediment for dune formation for many years to come, further expanding the area of desertified lands around Qinghai Lake.

Photo 2.30. Rape seed field, Qinghai Lake, Qinghai Province. Photo by Dawa Tsering.

2.7.3.5 Ecological Threats: Pasture Degradation and Desertification

A third, and perhaps presently the largest, reason for desertification in the Qinghai Lake basin is overgrazing caused by the three million head of livestock pastured in the basin (Yan and Jia 2003, cited in Li, Xu, Sun, Zhang, and Yang 2007). In the past, the quality of pastures in the Qinghai Lake region was very high and suitable for grazing all types of livestock, including specialized grazers like yaks. However, in order to expand exploitation of pasture resources in the region, many new herding operations were established in the Qinghai Lake basin beginning in the 1950s. Unfortunately, these new herding operations largely overlooked the carrying capacity and sensitive nature of grasslands in the basin, which led to overstocking of livestock and a chronic overgrazing problem around Qinghai Lake (Wang and Sun 1999). By one estimate, as of the late 1990s there were already 690 km^2 of degraded grasslands in the immediate vicinity of the lake, while in 2008 it was estimated that there were 1118 km^2 of land around the lake threatened with desertification due to overgrazing and global warming (Wang and Sun 1999, China Daily 2008). Furthermore, a July 2000 remote-sensing based study of grasslands immediately surrounding the northwest quadrant of Qinghai Lake found that, based on percent cover of unpalatable pasture vegetation, 77 percent of the grasslands in the 81 km^2 study area were degraded to some degree, with 27 percent of the study

area being slightly degraded (31-50 percent unpalatable species), 38 percent beingmoderately degraded (51-70 percent unpalatable species), and 13 percent being severely degraded (>70 percent unpalatable species) (Liu, Zha, Gao, and Ni 2004).

In terms of grassland productivity, an investigation from 1973 to 1980 in Haiyan County on the northeast shore of Qinghai Lake found that the average yield of palatable grasses decreased from 2190 kg/ha to 1437 kg/ha over this period, a decrease in pasture productivity of 34 percent (Wang and Sun, 1999). In total, this represents an annual loss of 178 million kg of pasture forage in Haiyan County or the equivalent of annual feed for about 121,700 sheep (Wang and Sun 1999). Although grass yield in Haiyan County decreased sharply during the study period, the number of livestock did not decrease at a corresponding rate. Consequently, Haiyan's grasslands are suffering from overgrazing and are failing to provide the county's livestock with adequate nutrition, which has lead to an attendant decrease in livestock productivity. For example, county records show that from 1958 to 1990, the average weight of a sheep decreased from 25 kg in 1958 to just 15-20 kg in 1990, while the annual wool harvest decreased from an average of 0.99 kg/sheep in the 1950s to just 0.72 kg/sheep in 1990 (Wang and Sun 1999).

2.7.3.6 Ecological Threats: Decline of Wildlife in the Qinghai Lake Basin

Wildlife populations in the Qinghai Lake basin have declined sharply over the past century due to a general deterioration of the basin environment resulting from human activities and climate change. As of the first decade of the 21st Century, there were over 97,000 human inhabitants, 3 million head of livestock, and 20,000 ha of land being actively farmed in the Qinghai Lake basin (Yan and Jia 2003, cited in Li, Xu, Sun, Zhang, and Yang 2007; Li, Xu, Sun, Zhang, and Yang 2007). Herding and farming have resulted in large-scale destruction of wildlife habitat in the lake basin due to overgrazing and conversion of pastures to cropland, while large-scale fragmentation of wildlife habitat has resulted from both farmers and herders fencing off their lands, in the process excluding formerly abundant wild ungulates herds from large tracts of pastureland in the basin. Today, livestock numbers in the lake basin far exceed wild ungulate numbers, forcing wildlife to compete at an extreme disadvantage with livestock for the basin's extremely limited, severely degraded, grass resources (Liu and Jiang, 2004). The species most severely affected by these developments has been the Przewalski's gazelle, which had a total population of just 114 individuals in 1998 that were confined to three isolated populations around the northern half of the lake (Jiang, Li, and Wang 2000). Further threats to wildlife around Qinghai Lake include hunting, overexploitation of the region's limited freshwater resources, human waste and contamination, and a general increase in aridity of the region that has led to the drying up of many of the region's natural water sources. Other wild animal species that are in decline or have been completely eliminated in the lake basin in the past century include the Tibetan wild ass, wild yak, white-lipped deer, and snow leopard (Schaller 1998).

Qinghai Lake's fish have also been threatened by increasing salinity as the lake's volume decreased over the past century. Other threats to the "naked" or "scale-less" carp, which is endemic to Qinghai Lake, include decades of commercial-scale overfishing and loss of spawning grounds resulting from diversion of rivers feeding the lake for irrigation (Walker and Yang 1999). In 1958, commercial trawling and gill-netting for naked carp began on Qinghai Lake, and the official catch peaked at 28,523 tonnes in 1960 but by 1965 had dropped to just 4000 tonnes, a level that was roughly maintained until 1980. After 1980, the annual catch declined further, and by 1990, the combined legal and illegal catch was estimated to be just 3,000 tonnes/year (Walker and Yang, 1999). Naked carp take seven years to reach sexual maturity and a minimum marketable size of about 300 g. But in 1992, random samples of the commercial catch showed that significantly over half of the fish caught were less than seven years old (Walker and Yang, 1999). This clearly indicates that fishing practices at Qinghai Lake in the 1990s were not sustainable, and it is estimated that the lake's population of naked carp declined by 90 percent in the second half of the 20th Century (Chen, Zhang, Tan, Wang, Qiao, and Chang 2009). However, estimates of naked carp biomass in Qinghai Lake made between 2002 and 2006 showed that the population of this species increased significantly during this period, which is attributed to improved management measures put in place to protect this species, including granting the naked carp "state-protected rare fish species" status (Chen, Zhang, Tan, Wang, Qiao, and Chang 2009).

As the populations of humans and livestock in the Qinghai Lake basin both continue to grow, pressure on the lake basin's extremely limited water, pasture, and wildlife resources, which are already under threat from global climate change, will also continue to grow, with the long-term consequences for the environment and wildlife of the lake basin expected to be severe.

2.8 Summary of the Impacts of Climate Change and Human Activities on the Wetlands and Biodiversity of the Qinghai-Tibet Plateau

2.8.1 Climate Change Impacts

Studies of temperature, precipitation, lake levels, and lake sediments on the Qinghai-Tibet Plateau have revealed a distinct trend of increasing temperature, a less distinct trend towards decreasing precipitation, and an overall increase in the rate of evaporation of surface water on the plateau over the past century (e.g. see Chapter 1 of this report; Li, Xu, Sun, Zhang, and Yang 2007; Zhu, Chen, Li, Li, Xia, and Li 2002). As discussed above, the impacts of this climatic warming trend on the wetlands of the Qinghai-Tibet Plateau have already been severe. These impacts have included not only increased evaporation and decreased precipitation, but also the rapid meltoff of glaciers that provide the source waters for many

plateau wetlands as well as the widespread degradation of permafrost that underlies many plateau wetlands and prevents deep infiltration of surface waters (e.g. see Chapters 3 and 4 of this report). As a result of these four factors, many seepage fields, streams, wetlands, ponds, and small lakes on the plateau have already dried up, and many more are threatened with a mass drying up. The widespread disappearance of surface water resources on the plateau will have severe consequences for both humans and wildlife inhabiting the Qinghai-Tibet Plateau, as well as for the economic development of the entire region.

2.8.2 Land Reclamation and Overuse of Water Resources

The intensive use of the Qinghai-Tibet Plateau's remote wetlands by humans is a relatively recent phenomena that only began on a large scale in the 1950s. One large impact humans have had on plateau wetlands, particularly on the Zoige Wetlands, has been through land reclamation using canals to artificially drain wetlands to create new pastures or cropland. In addition to eliminating large tracts of wet meadows and marshes, this practice has also had the effect of lowering groundwater levels, leading to the disappearance of seeps and streams well beyond the reclaimed area (He and Zhao 1999). At the same time, privatization and fencing of wetland pastures at Zoige has cutoff access to water for many herders, forcing them to overexploit perched groundwater tables which has led to further drying up of wet meadows. (Yan and Wu 2005). Another problem is that of ploughing reclaimed wet meadows for croplands under conditions of falling groundwater levels and climatic warming and drying, which can result in the eventual desertification of the lands involved (Liu and Zhang 2001). Reclamation of wetlands also permits the proliferation of small burrowing mammals, such as pikas, marmots, and voles, which may eventually colonize reclaimed areas leading herders to wrongly blame these animals for the loss of livestock forage and the destruction of their newly reclaimed pastures (Liu and Zhang 2001, Smith and Foggin 1999).

2.8.3 Overgrazing

In the arid interior of the Qinghai-Tibet Plateau, the well-watered meadows and wet meadows that surround ponds, lakes, and rivers are important pasture resources for both domestic livestock and wild ungulates. However, since the 1960s, these limited wetland pastures have been under increasing pressure due to the rapid growth in the numbers of both humans and livestock occupying them. This has led to the overstocking of these fragile pastures far beyond their carrying capacity and resulted in the general degradation of both pastures and wetlands themselves (Liu and Zhang 2001). As a consequence, widespread overgrazing of wetland pastures has occurred, resulting in the interruption of the life cycle of many wetland plant species and an overall loss of wetland plant diversity. This degradation of wetland ecosystems has also led to a diminished ability of wetlands to perform important ecosystem functions, such as improving water quality. As discussed above, over-

grazing of wet meadows at the Zoige Wetlands has resulted in a decrease in gramineous species, an increase in unpalatable species, and a general decline in grassland productivity.

2.8.4 Desertification

The combination of climate change, overgrazing, and land reclamation has led to desertification of many wetland areas of the Qinghai-Tibet Plateau. Climate change has led directly to desertification of wetland areas through decreased precipitation and increased rates of surface water evaporation that accompany increasing temperatures, the end result of which is the partial or complete drying up of rivers, wetlands, ponds, and lakes (Li, Xu, Sun, Zhang, and Yang 2007). In the case of Qinghai Lake, new lands exposed by falling lake levels are both sandy and salty, and consequently are incapable of supporting significant plant life, making them prone to rapid dune formation (see section 2.7.3.3, above). Perhaps a wider-scale problem leading to desertification of wetlands is that of overstocking of domestic livestock on meadows surrounding wetlands and the overgrazing that results. Grassland soils on the Qinghai-Tibet Plateau tend to be very thin and underlain by sand. Once denuded of protective vegetation, these sandy soils are exposed to strong winds that can rapidly cause dunes to form, as has occurred in recent decades in Gansu's Machu County (see section 2.7.2.3 above). In many instances, these sand dunes have overwhelmed wetland areas, burying and destroying wetland vegetation as well as irreversibly filling in portions of lakes and wetlands themselves, a problem that is further compounded by the draining of wetlands to create new pastures and farmlands as is done in areas of the Zoige Basin.

2.8.5 Decreased Levels of Wetland Soil Nutrients

As discussed in section 2.7.1.4, above, climatic warming and drying can actually have the effect of increasing the nutrient content of marsh soils by increasing the ability of aerobic microorganisms to transform insoluble nitrogen, phosphorus, and potassium into soluble forms that can be utilized by wetland vegetation. Regrettably, increased productivity of wetland vegetation under conditions of regional climate warming and drying is often overexploited by herding communities, whose more marginal pastures are often suffering from severe degradation and desertification. As a result, overexploitation of wetland ecosystems by humans and their livestock can ultimately lead to decreased levels of nutrients in wetland soils and an attendant decrease in wild plant and animal biodiversity (He and Zhao, 1999).

2.8.6 Peat Mining

As discussed in section 2.7.1.5, the large-scale mining of peat for fuel for power generation now threatens large tracts of wetland ecosystems in the Zoige Basin with complete destruction and will also radically alter the hydrological regime of the areas affected.

2.9 Recommendations

Wetlands of the Qinghai-Tibet Plateau are unique natural ecosystems that provide ecological services of international importance, such as providing a continuous source of water for major international rivers and contributing to the maintenance of regional biodiversity. Due to the changing nature of climatic conditions and human land-use activities on the plateau, action is now needed to protect these fragile, high altitude, wetland ecosystems. Therefore, the authors put forth the following recommendations for the protection and sustainable use of wetland ecosystems on the Qinghai-Tibet Plateau:

- Actively conduct expanded scientific research on the wetlands of the Qinghai-Tibet Plateau that places an emphasis on: 1) the various dynamic changes plateau wetlands are presently experiencing, 2) wetland ecosystems and their biodiversity characteristics, and 3) the biogeochemical cycles of plateau wetlands. Doing so will permit establishment of a scientifically sound basis for the rational conservation and utilization of plateau wetland resources.

- Based on our present scientific understanding of wetland ecology on the Qinghai-Tibet Plateau, develop a comprehensive, region-wide program to expand and improve present conservation measures to protect the plateau's wetland ecosystems, in particular with respect to maintaining their biodiversity and ecological functions.

- Since the degradation of wetlands on the Qinghai-Tibet Plateau is closely linked to climate change, human activities, and other regional ecological issues: 1) improve and expand all region-wide environmental protection efforts on the plateau, and 2) improve coordination and information sharing between wetland protection projects and other conservation projects active on the plateau, such as those examining the impacts of climate change or seeking to improve management of the plateau's rangelands, nature reserves, and water resources.

2.10 Conclusions

The extensive wetlands of the Qinghai-Tibet Plateau are the product of the plateau's numerous drainage basins and the relatively warm, moist climate that evolved after the end of the last glacial period. In the arid interior of the plateau, these wetlands are zones of remarkably high biodiversity amidst otherwise barren high altitude grasslands, with the Zoige Wetlands alone harboring 251 vertebrate species and 1208 species of higher plants (Liu and Zhang 2001; Xiang, Guo, Wu, and Sun 2009; He and Zhao 1999). In addition, the well-watered meadows surrounding these wetlands are a vital economic resource, providing some of the most important pastures for the nomadic livestock herders of the high plateau as well as providing a continuous source of freshwater for agriculture and power generation for millions of downstream users. Unfortunately, the continued existence of the Qinghai-Tibet Plateau's wetlands is under threat due to a combination of factors, including increased evaporation resulting from global climate change, desertification due to both climate change and overgrazing, other poor land-use practices, and the rapid meltoff of the plateau's glaciers and permafrost. If the wetlands of the Qinghai-Tibet Plateau are to be preserved for the benefit of future generations, a coordinated, long-term conservation effort involving scientists, conservationists, decision makers, and local residents will be required.

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3

Climate Change and its Impacts on Glacial Resources and Hydrological Cycles in the Yangtze Source Region

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3.1 Introduction

The source of the Yangtze River lies on the northern slope of the Tanggula Range in southwest Qinghai Province, in the very heart of the Qinghai-Tibet Plateau. The river originates at an elevation of 5480 m at the base of a glacier field on the 6513 m high Garkyagdeugang Peak, about 25 km to the west of the better known Geladandong Peak, which at 6621 m in elevation is the highest peak in the region. These peaks are just two of 21 snow-capped peaks over 6000 m in elevation in this part of the plateau that are the location of 40 major glaciers with a total surface area of 595 km^2 (Wang, Cheng, Shen, et al. 2001; Pu 1994 and 1995; Ding, Yang, Liu et al. 2003). The highest reach of the upper Yangtze River flowing off the Tanggula Range is known as the Tuotuo River, which is joined just east of the Qinghai-Tibet Highway by the Dam Chu River to form the Tongtian River, as the Yangtze is known for the remainder of its journey across Qinghai Province. The Chumda River Gage Station is located on the lower Tongtian, just before the river flows out of Qinghai Province, and marks the easternmost extent of the hydrological province that we hereafter refer to as the “Yangtze Source Region” (Photo 3.1) The Yangtze Source Region has an area of 137,704 km^2, accounting for about 8 percent of the Yangtze River’s entire watershed, and regulates the flow of the upper Yangtze west of the Sichuan

Photo 3.1. Tongtian River near the Chumda Bridge, Chindu County, Qinghai. Photo by Dawa Tsering.

Basin (Wang, Cheng, Shen, et al. 2001). As it passes through southern Qinghai Province, the Yangtze flows through a variety of ecosystems, primarily alpine steppe, wet meadows, and shrublands.

3.2 Geomorphic Features of the Yangtze Source Region

The terrain of the Yangtze Source Region decreases in elevation from west to east, with the major geomorphologic units of the region being: 1) the east-west trending Tanggula Range, which forms part of the southern boundary of the region and is composed of peaks that typically range from 5500-6000 m in elevation (Photo 3.2); 2) the high altitude Chang Tang steppe grasslands, which form the western and central Yangtze Source Region, a rolling plain that has an altitude typically ranging from 4500-5000 m and which is dotted with numerous lakes and wetlands; 3) the Hoh Xil and Kunlun Ranges, which form part of the northwestern boundary of the Yangtze Source Region; 4) the Bayan Har Mountains, which form the easternmost portion of the Yangtze Source Region; and, finally, 5) the Ulan Ul and Zurhen Ul Mountains, which form the northwest and southwest boundaries of the Yangtze Source Region, respectively (Wang, Cheng, Shen, et al. 2001).

Photo 3.2. Tanggula Range, Tanggula District, Qinghai Province. Photo by Dawa Tsering.

Other notable geomorphic features in the Yangtze Source Region include the valley of the Beilu River, a tributary of the Tongtian River located in the westernmost corner of Chumarleb County; the Chumar River Valley, the largest northern tributary of the Tongtian River, which flows some 500 km eastwards across the Chang Tang grasslands before joining the Tongtian in south-central Chumarleb County; the extensive wetlands of the Dam Chu River headwaters in south-central Zadoi County; and the gorge of the upper Gar Chu River (Wang, Cheng, Shen, et al. 2001).

3.3 Climate in the Yangtze Source Region

The Yangtze Source Region has a typical continental alpine climate that is generally cold and dry with intense sunshine and a large diurnal temperature variation, but which is affected by a strong, predictable summer monsoon (Feng, Tang and Wang 1998). The region only has two distinct seasons, a long cold season

from about mid-October to mid-May, and a shorter warm season lasting the remainder of the year. The high dry atmosphere of the Yangtze Source Region is extremely clear, resulting in intense radiational cooling each evening and a high rate of evaporation during the day.

Local climate data from Nangchen County, which actually lies in southern Qinghai's Mekong River basin but which is immediately adjacent to Jyekundo County, the easternmost county of the Yangtze Source Region, shows Nangchen to be the warmest county in the area, with an annual mean temperature of 3.8ºC, an average temperature in July of 13.2ºC, and an average temperature in January of -6.6ºC, the warmest and coldest months of the year, respectively (Wang, Cheng, Shen, et al. 2001). The maximum and minimum recorded temperatures at Nangchen were +28.0ºC and -25.8ºC, respectively, while in the west of the Yangtze Source Region, the annual mean temperature at the Tuotuo River Meteorological Station is -3.0ºC, with maximum and minimum recorded temperatures of 22.0ºC and -53.0ºC, respectively (see Appendix C for locations of all meteorological stations on the Qinghai-Tibet Plateau). The Wudaoliang Meteorological Station, which is located about 120 km southwest of Kunlun Pass on the Qinghai-Tibet Highway in western Chumarleb County, has an annual mean temperature of -5.5ºC, with average minimum temperatures of -23.7ºC in January, and 0.2ºC in July (Yan, Yang, and Wang 2006; Wang, Cheng, Shen, et al. 2001).

Surface temperature records from the Tuotuo River, Wudaoliang, Yushu, and Chumarleb Meteorological Stations show that the Yangtze Source Region has experienced a significant warming trend since temperature data began to be collect-

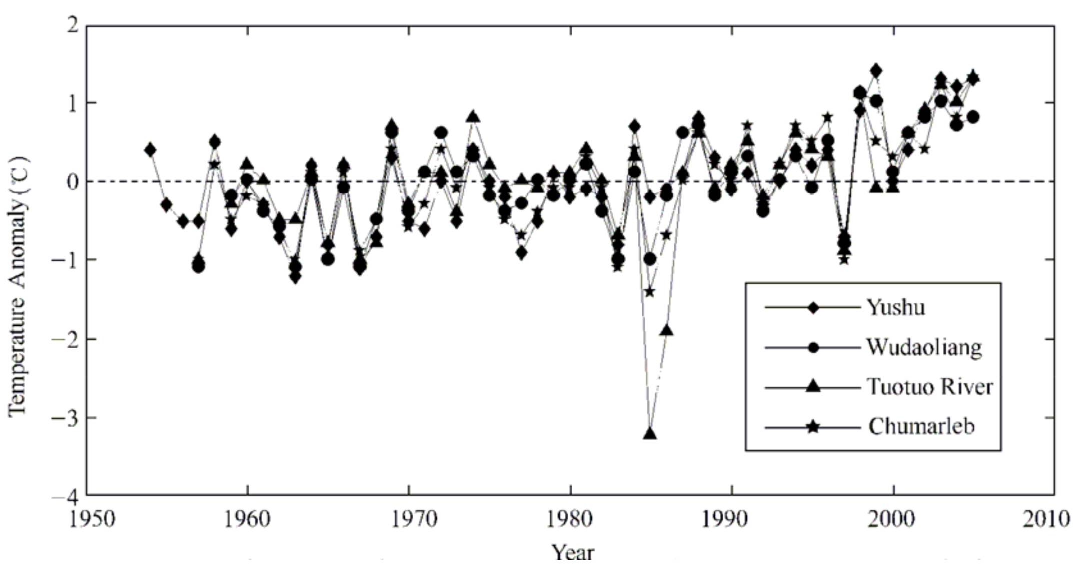

Figure 3.1. Variation from annual mean temperatures at the Tuotuo River, Wudaoliang, Yushu, and Chumarleb Meteorological Stations, 1956-2004.
Source: Kang, Zhang, Qin, et al. 2007 and Yang, Ding, Shen, et al. 2004.

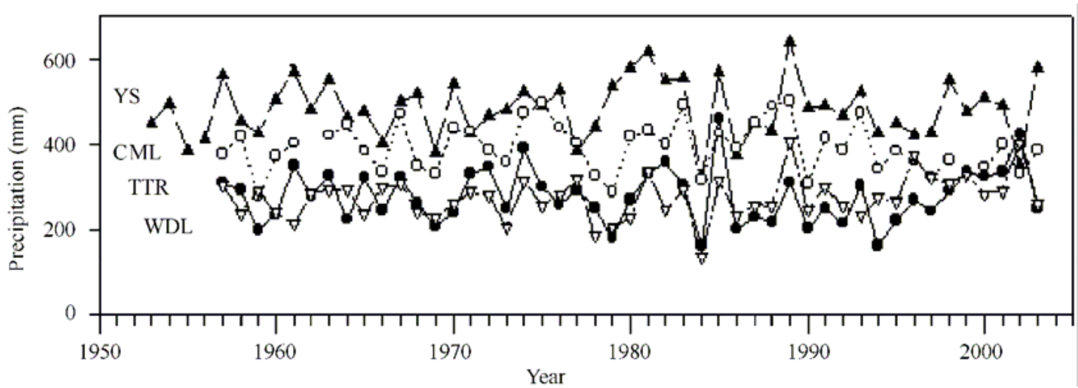

Figure 3.2. Interannual variability of precipitation at the Wudaoliang, Tuotuo River, Chumarleb, and Yushu Meteorological Stations in the Yangtze Source Region, 1953-2003.
Note: white triangle: Wudaoliang, black circle: Tuotuo River, white circle: Chumarleb, black triangle: Yushu.
Source: Yang, Ding, Shen, et al. 2004.

ed in 1956 (Fig. 3.1) (Kang, Zhang, Qin, et al. 2007; Yang, Ding, Shen, et al. 2004).

During the period from 1956-2004, the Wudaoliang, Tuotuo River, Chumarleb, and Yushu Meteorological Stations had annual mean precipitation of 275 mm, 278 mm, 394 mm, and 482 mm, respectively (Fig. 3.2) (Yang, Ding, Shen, et al. 2004). Although there were abnormally high and low precipitation years for each station, there were no distinct multi-year wet or dry periods between 1956 and 2004. However, a precipitation analysis for these four stations did reveal that precipitation patterns occurred in 3.4 year cycles (Wang 2004). Thus, over the past 50 years, precipitation in the Yangtze Source Region has not shown a distinct trend, although in recent years some individual stations in the region have shown significant increases in precipitation. For example, precipitation at the Tuotuo River Meteorological Station has exhibited a linearly increasing trend in precipitation from 1994 to 2003, with an average annual increase in precipitation of 13.6 mm/year over this period. (Fig. 3.2) (Yang, Ding, Shen, et al. 2004).

3.4 Rivers of the Yangtze Source Region and Their Hydrology

The four most important rivers of the Yangtze Source Region are the Tongtian, or upper Yangtze River, and the Tongtian River's three largest tributaries, the Chumar River to the north, the Tuotuo River to the west, and the Dam Chu River to the south. In addition, the Tongtian River basin also has 340 other significant

tributaries and a dense network of secondary and tertiary tributaries (Wang, Cheng, Shen, et al. 2001).

3.4.1 The Tuotuo River - Source of the Yangtze

The 350 km long Tuotuo River is the Yangtze's source river, being formed from several upper branches which flow off the Tanggula Range in the southwest corner of Qinghai Province (Table 3.1, Photo 3.3). The Tuotuo River watershed has an area of 17,600 km^2, which includes 381 km^2 of glacier cover, the highest part of which is formed by the perennially snow-covered northern slopes of Garkyagdeugang and Geladandong Peaks (Pu 1994 and 1995). At its source, the Tuotuo is fed by meltoff from five large glaciers, which gathers to form the highest reach of the 6380 km long Yangtze River, a stream that is known locally as the Nachin Chu.

Photo 3.3. Tuotuo River in flood, Tuotuo River Bridge, Qinghai-Tibet Highway, Tanggula District, Qinghai Province. Photo by Dawa Tsering.

The Nachin Chu flows off the Tanggula Range through a 6 km long glacially carved canyon, being joined by 25 other streams en route, before entering the steppe grasslands at the foot of the range (Table 3.1). The Nachin then flows northward for a further 24 km before being joined by the Qiesumei Chu, which enters from the west to form the Tuotuo River. At the junction of the Nachin and Qiesumei Chu Rivers, the Tuotuo River has a braided channel with a total width of 250 m and an annual mean flow rate of 12.12 m^3/s (Wang, Cheng, Shen, et al. 2001). The Tuotuo is then joined by the Lariganmuzhangba River and flows through a canyon of the Zurhen Ul Range before being joined by a number of streams flowing off the 6137 m high Gangqin Peak to the west. One-hundred and thirty kilometers from its source, the Tuotuo is joined by its next important tributary, the Jiangta Chu, which enters from the west where the Tuotuo River turns abruptly east to enter a Cenozoic fault basin. This fault basin is characterized by abundant high salt content sediments originating from the neighboring Mazhang Cuoqin and Yaxi Cuo Lakes, which cause a high degree of mineralization of the Tuotuo's waters, as much as 3 g/l (Wang, Cheng, Shen, et al. 2001). The Tuotuo River then cuts eastwards through the Mazhangyongma Mountains before turning south to be joined by the Wuguo Chu, Nianri Chu, and Balongchin Chu Rivers, and then flows a further 170 km eastward to be joined by the Niang Chu River. Finally, after flowing 350 km from its source, the Tuotuo River merges with the Dam Chu River in the sedimentary hills of the Nangjibalong Region to form the Tongtian or upper Yangtze River. At the junction of these two rivers, the Tuotuo has a width of

Table 3.1 Tributaries and features of the Tuotuo River, the source of the Yangtze

Tributary or Feature	Distance from Source (km)	Notes
Nachin Chu River, Source of the Tuotuo	0	Glacier at an elevation of 5480 m on Garkyagdeugang Peak
Glacially Carved Canyon, 25 Tributary Streams	0-6	
Enters Steppe Grasslands	6	
Qiesumei Chu	24	Enters via the Left Bank Width at Junction: 250 m Mean Flow Rate at Junction: 12.12 m^3/s
Lariganmuzhangba River		
Canyon of the Zurhen Ul Range		
Streams Flowing off Gangqin Peak, Elevation 6137 m		Enter via the Left Bank
Jiangta Chu	130	Enters via the Left Bank
East-West Trending Cenozoic Fault Basin, Mazhangyongma Mountains		
Wuguo Chu		
Nianri Chu		
Balongchin Chu River		
Niang Chu River	~300	
Dam Chu	350	Enters via the Right Bank to form the Tongtian River
Tuotuo River Flow Statistics	350	Annual Mean Flow Rate: 29.1 m^3/s Mean Total Annual Flow Volume: 918 million m^3
Tuotuo River Dimensions	350	Width of Tuotuo at the Dam Chu Junction: 60 m Depth of Tuotuo at the Dam Chu Junction: 1 m

Source: Wang, Cheng, Shen, et al. 2001.

60 m, a depth of about one meter, an annual mean flow rate of 29.1 m^3/s, and an annual mean flow volume of about 918 million m^3 (Wang, Cheng, Shen, et al. 2001). In total, the Tuotuo River has 97 primary tributaries, of which 10 have watersheds ranging from 300 to 1000 km^2 in size, while three have watersheds greater than 1000 km^2 in size (Wang, Cheng, Shen, et al. 2001).

3.4.2 The Dam Chu River - Southern Source of the Yangtze

The Dam Chu River is the southern source of the Yangtze and has by far the largest flow volume of any tributary of the Tongtian River. The watershed of the Dam Chu is 30,700 km^2 in size, which includes parts of Yushu Prefecture's Zadoi and Zhidoi Counties as well as part of southwestern Qinghai's Tanggula District (Wang, Cheng, Shen, et al. 2001). The source of the Dam Chu River is located roughly 220 km east of the Qinghai-Tibet Highway in the eastern Tanggula Range, where the river begins its journey to the sea from a spring at an elevation of 5050 m on the 5395 m high, glacier-free, Xiasheriaba Peak. From this spring the Dam Chu River meanders 351 km to the northeast before joining the Tuotuo to form the Tongtian River.

Table 3.2 Tributaries and features of the Dam Chu River, the "southern source" of the Yangtze

Tributary or Feature	Distance from Source (km)	Notes
Source of the Dam Chu	0	Spring at an elevation of 5050 m on Xiasheriaba Peak
Ponds and Marshes		
Riairineng River	8.1	
Zhaxigejun River	13.1	
Bianenghou River	34.3	
Gangaisenqu River	37.1	Enters via the Left Bank
Vast Open Marsh Complex	44.1	
Duoren Chu River	73.6	
Bencao Chu River	75.2	Enters via the Left Bank
Sadang Chu River	90.2	Enters via the Left Bank
Dam Chu River Width and Depth	150.2	Width of the Dam Chu: 28-42 m Depth of the Dam Chu: 1.2 m
Chadang Chu River	150.2	Enters via the Left Bank
Wuqin Chu River		Enters via the Left Bank
Chawu Chu River		Enters via the Left Bank
Gor Chu River		Enters via the Right Bank
Canyon		Dam Chu enters a canyon
Dun Chu	247.6	Enters via the Left Bank
Tian Chu		Enters via the Left Bank
Mariandazhou Chu		Enters via the Right Bank
Eaxigongkawu River		Enters via the Left Bank
Paleogene Red Basin		Dam Chu enters a Paleogene Red Basin
Bi Chu River	321.8	
Junction of the Tuotuo River	351	Tongtian (Upper Yangtze) River begins at this junction
Dam Chu River Flow Statistics	351	Annual Mean Flow Rate: 146 m^3/s Mean Total Annual Flow Volume: 46.06×10^8 m^3 River Flow Sand Content: 1.92 kg/m^3

Source: Wang, Cheng, Shen, et al. 2001.

Near its source at the base of the Tanggula Range, the Dam Chu flows through a series of ponds and large marshes where it increases greatly in size (Table 3.2). From source to mouth, notable tributaries of the Dam Chu include the Riairineng River, which enters at km 8.1 along the Dam Chu's course, the Zhaxigejun River, which enters at km 13.1, and the Bianenghou River, which enters from the left bank at km 34.3. At km 37.1, the Gangaisen Chu River enters along the left bank, at km 44.1, the Dam Chu enters a vast open marsh complex where it increases even further in volume, while the Duoren Chu River enters at km 73.6, the Bencao Chu River joins the Dam Chu's left bank at km 75.2, and the Sadang Chu River enters along the Dam Chu's left bank at km 90.2. At km 150 from its source, a series of streams empty into the Dam Chu along its left bank, including the Chadang Chu, Wuqin Chu, and Chawu Chu Rivers, while the Gor Chu enters via the right bank. At this point in its course, the river is 1.2 m deep and varies in width from about 28 to 42 m as it enters a canyon that further on forms the boundary between Yushu Prefecture and the Tanggula District. The flow of the Dam Chu increases again with

the entrance of a stream called the Mariandazhou Chu, which enters via the Dam Chu's right bank, while the Dun Chu and Tian Chu Rivers enter along the Dam Chu's left bank at about km 247 from its source. The Eaxigongkawu River then enters along the Dam Chu's left bank before the Dam Chu flows into a Paleogene red basin and continues northwards to Qirijiangma Mountain, where at km 321.8 the Bi Chu enters the Dam Chu (Photo 3.4). After its junction with the Bi Chu, the Dam Chu flows a further 29 km northeastwards to the Nangjibalong Region, where it joins the Tuotuo to form the Tongtian River (Wang, Cheng, Shen, et al. 2001).

Photo 3.4. Bi Chu River, Tanggula District, Qinghai Province. Photo by Dawa Tsering.

At its junction with the Tuotuo, the Dam Chu has an annual mean flow rate of 146 m^3/s, an annual mean flow volume of 46.06×10^8 m^3, and a sand content that is typically 1.92 kg/m^3 (Wang, Cheng, Shen, et al. 2001). In total, the Dam Chu River has 85 primary tributaries, the drainages of which make up nearly half of the Dam Chu Basin, six of which have watersheds greater than 1000 km^2 in size. The Dam Chu River basin also has extensive areas of marshes and snowfields and is thus well endowed with water resources (Wang, Cheng, Shen, et al. 2001).

3.4.3 The Chumar River - Northern Source of the Yangtze

The most important northern tributary of the Tongtian River is the Chumar River, which flows 527 km across the steppe grasslands of southwestern Qinghai's Zhidoi and Chumarleb Counties. The source of the Chumar is located at an elevation of 5301 m in the Hoh Xil Range, where it flows forth from the base of a glacier about 15 km to the southwest of Hoh Xil Lake in western Zhidoi County (Pu 1994 and 1995; Pu, Yao, Wang, Su, and Shen 2004; Wang, Cheng, Shen, et al. 2001). Ninety-six kilometers from its source, the Chumar flows into Elsen Nur Lake before exiting the lake a further 20 km to the east. One-hundred and twenty kilometers from its source, the Chumar passes under the Qinghai-Tibet Highway, then flows for 407 km across western Chumarleb County before joining the Tongtian River just south of Chumar River Township. The Chumar River drains a watershed 20,800 km^2 in size which includes 57 primary tributaries, only three of which have watersheds greater than in 1000 km^2 in size (Wang, Cheng, Shen, et al. 2001).

3.4.4 The Tongtian River (Dri Chu) – The Main Trunk of the Upper Yangtze in Qinghai Province

About 40 km southeast of the Tuotuo River Bridge on the Qinghai Tibet-Highway, the Tuotuo and Dam Chu Rivers join to form the Tongtian River, literally "the river leading to heaven," as the longest reach of the Upper Yangtze in Qinghai Province is known (Photo 3.5). For 828 km the Tongtian flows in an arc through the heart of Yushu Prefecture before exiting Qinghai Province to form the border between the Tibet Autonomous Region (TAR) and Sichuan Province, where the Yangtze is known as the Jinsha or "Gold Sand" River. From an elevation of 4470 m at its point of origin, the Tongtian flows through central Zhidoi County before forming the boundary between Zhidoi and Chumarleb Counties, and further downstream the boundary between Jyekundo and Chindu Counties. While gently meandering across the eastern edge of the Chang Tang steppe grasslands as a wide braided river for the first third of its course, shortly after its junction with its largest tributary, the Chumar River, the Tongtian becomes a rapid-filled, single-channel river flowing through a series of narrow mountain canyons. In the first 280 km after its junction with the Chumar, the Tongtian drops 254 m, a gradient of 0.09 percent (Wang, Cheng, Shen, et al. 2001).

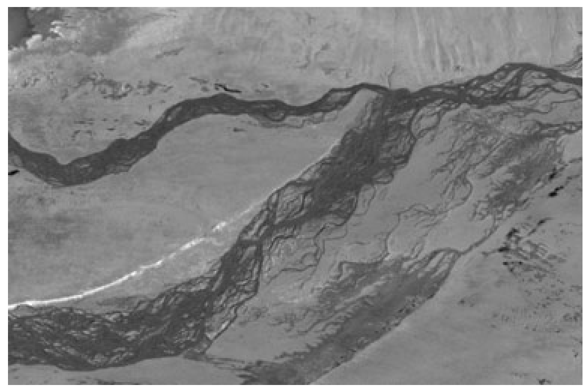

Photo 3.5. Tongtian River (far right) at the Junction of the Tuotuo (above) and Dam Chu (below) Rivers, Zhidoi County, Qinghai Province. NASA Landsat Image.

The upper half of the Tongtian River has a well developed network of tributary streams, including 101 primary tributaries, seven of which have watersheds greater than 1000 km^2 in size, the Chumar, Ranchi Chu, Mug Chu, Yag Chu, Beilu, Kugchen Chu, and Lechi Chu Rivers, as well as three additional large tributaries with watersheds ranging from 300 to 1000 km^2 in size, the Dongbuli Chu, Daha Chu, and Xiaeba Chu Rivers (Wang, Cheng, Shen, et al. 2001).

3.4.5 Hydrology of Rivers in the Yangtze Source Region

A number of river gage stations have been set up along the Qinghai-Tibet Highway since June of 1958, including four on rivers in the Yangtze Source Region, the Chumar River Station, the Tuotuo River Station, the Deliechuka Station on the Gar Chu River, and the Yanshiping Station on the Bi Chu River. These four stations have been operating for nearly 50 years, collecting river flow data which

Table 3.3 Hydrologic values for river gage stations in the Yangtze Source Region

River	Station Name	Location	Catchment Area Upstream of Station (km^2)	Annual Mean Flow Rate (m^3/s)	Annual Mean Runoff Volume (x 100 million m^3)	Annual Mean Runoff depth (mm)
Bi Chu River	Yanshiping	33°35' N 92°06' E	4538	24.9	7.86	173.7
Chumar River	Chumar River	35°20' N 93°20' E	9388	7.46	2.35	25.1
Gar Chu River	Deliechuka	33°50' N 92°22' E	4166	24.6	7.76	186.3
Tongtian River	Chumda	33º01' N 97º14' E	137,704	397	125.2	88.7
Tuotuo River	Tuotuo River	34°13' N 92°26' E	15924	25.0	7.88	49.5

Source: Wang, Cheng, Shen, et al. 2001 and the Qinghai Hydrological and Water Resource Bureau.

Table 3.4 Lengths, watershed areas, and flow volumes of the four largest rivers in the Yangtze Source Region.

River	Length (km)	Watershed Area (km^2)	Annual Flow Volume (x 1,000,000 m^3)
Dam Chu	351	30,700	4600
Chumar	527	20,800	1039
Tuotuo	350	17,600	918
Tongtian (Entire Yangtze Source Region)	828	137,704	9818

Source: Wang, Li, Cheng, and Shen 2001.

can be used to study the hydrological trends of major rivers in the Yangtze Source Region (Table 3.3).

In addition to rivers, the Yangtze Source Region also has abundant surface water resources in the form of glaciers, snowfields, lakes, and wetlands, with glacial meltwater and precipitation being major sources of surface water flow. Thus, the amount of surface flow in the region in any given year is dependent on both air temperature and precipitation, with annual peak flows generally occurring in late summer and early autumn. At the end of the 1990s, the entire Yangtze Source Region was generating an annual mean runoff volume of about 9.818 billion m^3, of which the Tuotuo River accounted for 918 million m^3, the Dam Chu River for 4.6 billion m^3, the Chumar River for 1.039 billion m^3, and the upper streams of the Tongtian River for 3.255 billion m^3 (Table 3.4) (Wang, Li, Cheng, and Shen 2001).

In terms of long-term runoff distribution patterns, the Tuotuo and Chumda River Gage Stations, which are located at the upstream and downstream ends of the Yangtze Source Region, respectively, had similar runoff distribution patterns during the period from 1961-2005. Most flow at these two stations is concentrated in July and August, although the peak of annual flow at the Chumda Station on the

Tongtian River lags behind that of the Tuotuo River Station somewhat, while runoff at the Tuotuo River Station is much more concentrated than that at the Chumda Station, with a more uneven annual distribution. However, both stations recorded relatively higher total annual runoff volumes during the 1960s, which was followed by a later period of decline in annual runoff volumes at both stations.

In the case of the Tongtian River, from 1958 through the 1980s, the annual flow volume of the Tongtian exhibited an increasing trend, which was immediately followed by a declining trend in flow volume that lasted through the 1990s (Yan, Yang, and Wang 2006). This decline in the Tongtian's annual flow volume was presumably due to reduced summer rainfall, increasing temperatures, and subsequently increased rates of evaporation in the Yangtze Source Region. However, even during this period of declining annual runoff volumes, flow in the Tongtian was relatively stable, and these declines were the lowest amongst large rivers under varying climatic conditions in China during this period (Yan, Yang, and Wang 2006). With respect to the 30-year reference flow volume for the 1971-2000 period, the Tongtian River's surface runoff volume decreased by a total of 11.1 billion m^3 on a combined basis during the 1990s, although on a combined basis it actually registered a modest increase of 1.276 billion m^3 from 2000-2003 (Yan, Yang, and Wang 2006). Thus, in total, the surface runoff volume of the Tongtian River decreased by 9.824 billion m^3 from 1990 to 2003 with respect to the 1971-2000 30-year reference period.

In summary, over the entire period covered by the river gage record for the Tongtian Basin, the basin became increasingly wetter from 1958 through the 1980s and increasingly dryer during the 1990s, which was followed by a recent period of modestly increasing wetness from 2000-2003. During May, the transitional month between dry season and wet season in the Yangtze Source Region, recent trends indicate that modest increases in snowfall, rainfall, and glacier meltoff have occurred in the region (Wang, Cheng, Shen, et al. 2001).

3.5 Glacier Resources in the Yangtze Source Region

The Yangtze Source Region has one of the largest concentrations of glaciers on the Qinghai-Tibet Plateau, with 627 glaciers being found in the region (Table 3.5). These glaciers had a total area of 1168 km^2 in 1969, and account for 47.1 percent of the total number of glaciers and 61.1 percent of the total glacier cover in the entire Yangtze River basin (see Appendix E for the distribution by river basin of all glaciers in the Yangtze River basin) (Pu 1994 and 1995; Shi, Liu, and Wang 2005). Most glaciers in the Yangtze Source Region are concentrated in three areas, on the northern slope of the Tanggula Range, on the southern slope of the Kunlun Range, and on Sederi Peak, which is located about 70 km southwest of the Zhidoi County Seat (Fig. 3.3) (Yao 2008). Based on established relationships between glacier area,

thickness, and volume, the volume of glacial ice in the Yangtze Source Region is estimated to be 98.3 km^3, or the equivalent of 84 billion m^3 of water. This volume of water is about 6.7 times the Yangtze Source Region's annual mean runoff volume of 12.52 billion m^3, as recorded at the Chumda River Gage Station over the period from 1961-2000, and accounts for 66.8 percent of the total volume of glacial ice in the entire Yangtze River basin (Pu 1994 and 1995; Shi, Liu, and Wang 2005).

Table 3.5 Distribution of major glacier systems of the Yangtze Source Region by river basin

River Basin	River Basin Code	River Sub-basin	Number of Glaciers	Area of Glaciers (km^2)	Volume of Glaciers (km^3)
Kugchen Chu River	5K431E	Kugchen Chu	18	12.65	0.5459
	5K431D	Mo Chu	1	0.2	0.0034
	5K431H	Shicho Chu	1	0.48	0.0149
Dam Chu River	5K441H	Sha Chu	13	6.16	0.2226
	5K441I	Wuqin Chu	15	6.41	0.2034
	5K441J	Chawu Chu	18	10.7	0.4069
	5K441K	Eamanacao Chu	52	36.59	1.5464
	5K441M	Tian Chu	121	154.26	8.5037
	5K441N	Parronglangna Peak	2	0.53	0.0101
Dong Chu River	5K442C	Zuria	44	48.36	2.6611
	5K442D	Gaimalong	3	5.4	0.3145
Bi Chu River	5K443B	Chaqin Chu	4	3.92	0.1582
	5K443C	Shasairi	18	12.59	0.5034
	5K443D	Rongma Chu	61	114.9	9.002
	5K443E	Bi Chu River Source	13	30.38	2.1742
	5K443F	Quezai Chu River	21	33.94	2.5744
Gar Chu River	5K444B	Gar Chu River	83	254.53	24.9014
Tuotuo River	5K451F	Tuotuo River	76	375.2	41.4906
	5K451G	Jiangta Chu	6	4.13	0.1827
	5K451K	Zhamu Chu	2	5.93	0.3586
Ranchi Chu River	5K452D	Daha Chu	2	0.34	0.0053
	5K452E	Sairuoduo	1	0.51	0.0128
	5K452G	Xiaeba	5	2.98	0.0965
Chumar River	5K463C	Baladacai Chu	8	9.65	0.4461
	5K463D	Yuzhu Peak	12	16.09	0.9539
	5K463G	Zharigana Chu River	27	21.35	1.0096
Total			627	1168.18	98.3026

Source: Pu 1994 and 1995; Shi, Liu, and Wang 2005.

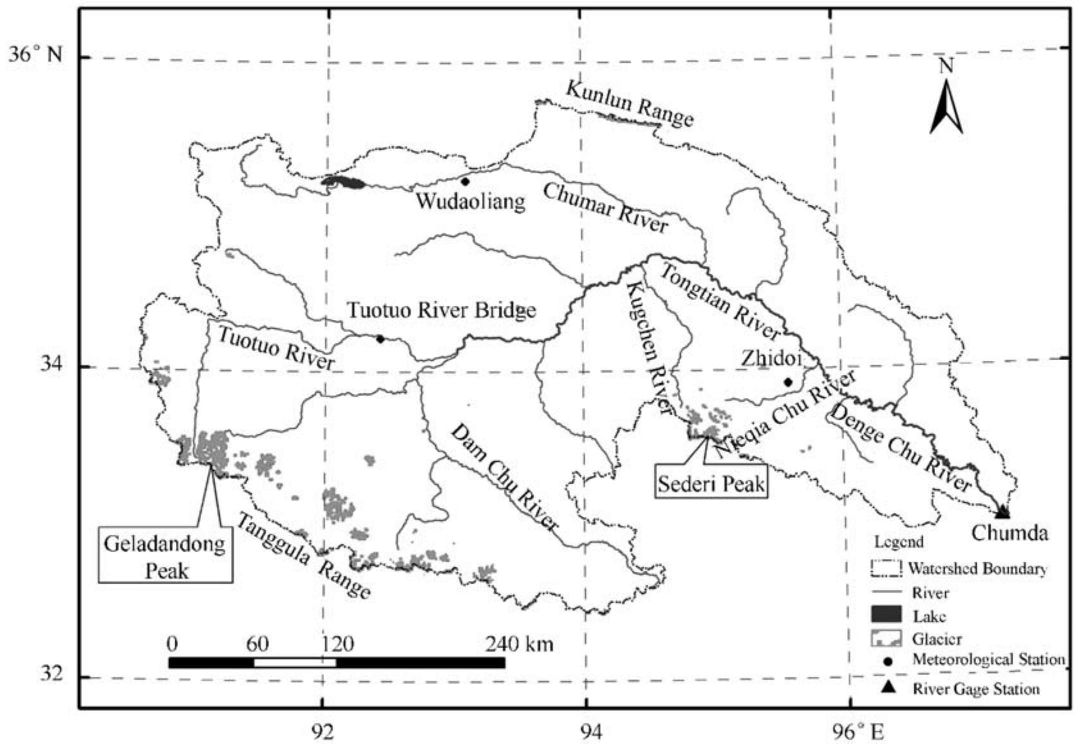

Figure 3.3. Distribution of glaciers in the Yangtze Source Region.
Source: Xu, Liu, and Zhang 2009.

Table 3.6 Distribution of glaciers in the Yangtze Source Region by mountain range

Mountain Range	Elevation of Highest Peak (m)	Number of Glaciers	Area (km^2)	Volume (km^3)	Mean Area (km^2)	Elevation of Snow Line (m)	Minimum Elevation of Glaciers (m)
Tanggula	6621	520	1021.02	87.3812	1.96	5360-5880	5120
Yuzhu Peak	6178	47	47.09	2.4096	1.0	5250-5440	5010
Zurhen Ul	6137	30	76.98	7.4744	2.57	5000-5660	5200
Sederi Peak	5876	18	12.65	0.5459	0.70	5280-5320	5040
Dongbuli	5661	8	3.83	0.1146	0.48	No Data	5120
Ulan Ul	5717	2	5.93	0.3586	2.97	No Data	No Data
Xiqiaorisheng	5651	2	0.68	0.0183	0.34	No Data	No Data
Total	(max. 6621)	627	1168.18	98.3026	1.86	5250-5880	(min. 5010)

Source: Pu 1994 and 1995; Shi, Liu, and Wang 2005.

The majority of glaciers in the Yangtze Source Region are found on the northern slope of the Tanggula Range, where 520 glaciers with a total surface area of 1021 km^2 and a total ice volume of 87.4 km^3 are found. These glaciers represent 83

Table 3.7 Glaciers of the Yangtze Source Region >10 km^2 in area, all located in the Tanggula Range

Glacier Code	River Basin	Glacier Area (km^2)	Length (km)	Orien-tation	Maximum Glacier Elevation (m)	Mid-Point Glacier Elevation (m)	Equilibrium Line Elevation (m)	Minimum Glacier Elevation (m)	Glacier Volume (km^3)
5K443D31	Bi Chu	19.35	7	W	6000	5620	5560	5240	2.2833
5K443D38	Bi Chu	16.52	5.4	S	6104	5680	5600	5280	1.8520
5K443F17	Bi Chu	13.78	5.6	SE	5947	5660	5570	5260	1.4607
5K444B10	Gar Chu	17.12	8.2	NW	6016	5600	5600	5200	1.9346
5K444B41	Gar Chu	31.34	8.6	E	6338	5800	5780	5380	4.3249
5K444B44	Gar Chu	23.87	9.5	SE	6361	5860	5740	5340	3.0315
5K444B64	Gar Chu	37.44	10.8	E	6621	5940	5820	5600	5.4662
5K444B72	Gar Chu	14.29	4.8	NE	6621	5800	5680	5360	1.529
5K444B80	Gar Chu	12.54	6.7	NE	6150	5740	5660	5200	1.2791
5K451F2	Tuotuo	10.86	5.6	N	6047	5680	5600	5280	1.0643
5K451F5	Tuotuo	15.18	6	NW	6290	5740	5720	5320	1.6546
5K451F8	Tuotuo	52.92	9.9	NW	6621	5760	5680	5360	8.6789
5K451F9	Tuotuo	16.91	7.4	NE	6060	5760	5640	5320	1.9018
5K451F30	Tuotuo	31.4	10.1	W	6543	5820	5820	5400	4.3332
5K451F33	Tuotuo	34.77	12.4	SW	6543	5860	5840	5395	4.9721
5K451F38	Tuotuo	10.22	5.9	E	6327	5760	5740	5360	0.9811
5K451F40	Tuotuo	10.42	5.2	SE	6257	5760	5730	5400	1.0003
5K451F47	Tuotuo	12.93	6.3	NE	6087	5680	5530	5340	1.3318
5K451F67	Tuotuo	12.38	5.2	N	6137	5640	5620	5350	1.2628
5K451F69	Tuotuo	30.76	8.4	N	6012	5640	5660	5320	4.2141

Source: Pu 1994 and 1995; Shi, Liu, and Wang 2005.

percent of the total number of glaciers, 87 percent of the total glacier area, and 89 percent of total glacial ice volume in the Yangtze Source Region as well as 39 percent of the total number of glaciers, 54 percent of total glacier area, and 59 percent of total glacial ice volume in the entire Yangtze River basin (Table 3.6) (Pu 1994 and 1995). Six of these glaciers have areas greater than 30 km^2, all of which occur on or near Geladandong Peak, the highest peak in the Tanggula Range, while of 20 glaciers larger than 10 km^2 in area, 11 are located in the Tuotuo River basin with the remaining nine being located in the Gar and Bi Chu drainages of the Dam Chu River basin (Table 3.7) (Pu 1994 and 1995).

3.6 Changes in Yangtze Source Region Glaciers in Response to Climate Change

3.6.1 Recent Temperature Fluctuations in the Yangtze Source Region

Climate change is the primary reason behind fluctuations in the size of glaciers (Gao, Tang, and Feng 2000; Wang and Zhang 1992). Studies of ice cores from the Dongkemadi Glaciers, located near Tanggula Pass in Qinghai Province, the Guliya Ice Cap in the western Kunlun Range, and the Malan Ice Cap in the Hoh Xil region of Qinghai have all found that temperature variations recorded by $\delta^{18}O$ oxygen

isotopes at these locations correspond closely with measured annual temperature fluctuations in the region as a whole (Photos 1.3, 3.6, and 3.7) (Yao 1998; Wang, Yao, Pu, Zhang, Sun, and Wang 2003). From the late 1950s to the early 1960s, the climate of the Yangtze Source Region experienced a relatively warm period, which was immediately preceded and followed by relatively colder periods, the latter of which ended in 1969. In the late 1970s, a period of more or less continuously increasing temperatures began, which is consistent with observational data collected in western China at this time (e.g. see Fig. 3.1). The findings of tree-ring studies have shown that two recent episodes of significant climatic warming have occurred on the Qinghai-Tibet Plateau, from the 1920s-1940s and from the mid-1970s to the present, with the last two decades of the 20th Century having been exceptionally warm on the plateau (Tang, Bai, and Liu 1998; Liu 1998).

Photo 3.6. Dongkemadi Ice Field, Tanggula Pass, Tanggula District, Qinghai. Photo by Dawa Tsering.

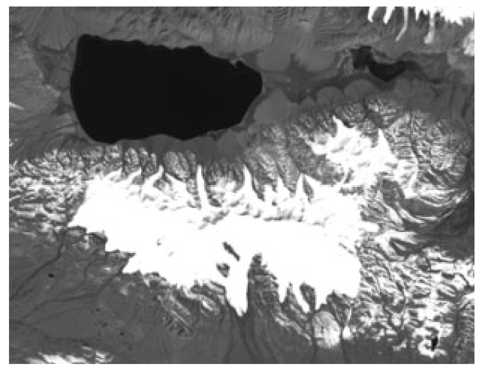

Photo 3.7. Malan Ice Cap, Zhidoi County, Qinghai. NASA Landsat image.

3.6.2 <u>Advance and Retreat of Glaciers in the Yangtze Source Region</u>

Both climate fluctuations in the past century and climate warming over the last several decades have caused glacier terminuses in the Yangtze Source Region to shift, sometimes dramatically, with the advance or retreat of glaciers in the region serving as an important indicator of climatic changes. The advance and retreat of glaciers is closely associated with both climatic conditions and glacier type, and glaciologists generally believe that there is a time lag in the response of glaciers to climate change, with smaller glaciers usually having shorter time lags than larger ones (Gao, Tang, and Feng 2000; Wang and Zhang 1992).

Since the 1990s, most formerly advancing glaciers in the Yangtze Source Region have begun retreating. For example, in 1991 the Large and Small Dongkemadi Glaciers had areas of 14.63 km^2 and 1.77 km^2, respectively, and both were advancing at that time (Photo 3.6) (Yao, Wang, Liu, Pu, Shen, and Lu 2004). However, both have been retreating since the mid-1990s (Fig. 3.4). The Small Dongkemadi Glacier began retreating in 1995, and the rate of retreat of this glacier has, for the most part, increased with time, with the glacier retreating 2.86 m in

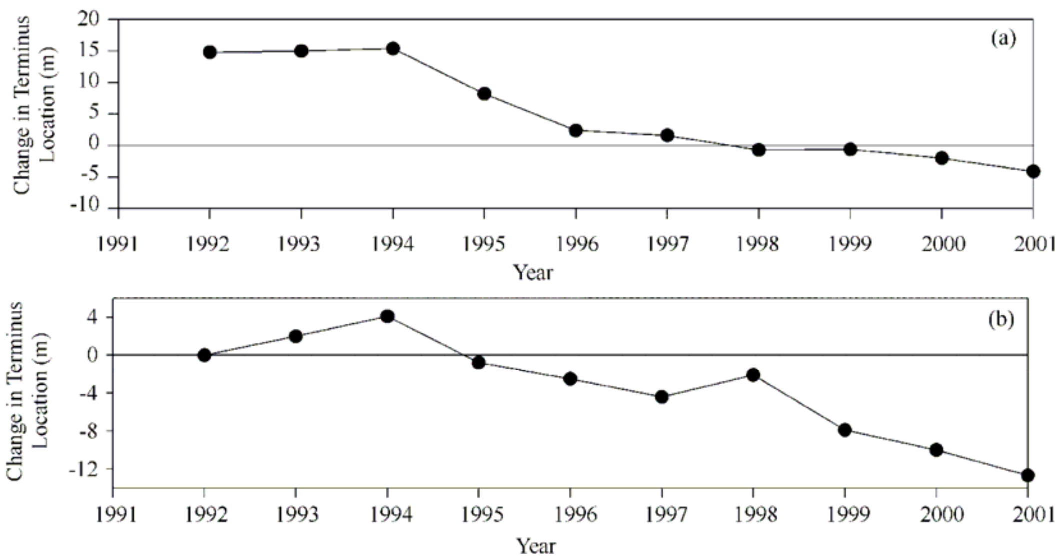

Figure 3.4. Yearly location of the terminus of the Large and Small Dongekemadi Glaciers with respect to "zero points" set at beginning of measurements, 1992-2001. (a): Large Dongkemadi Glacier, (b): Small Dongkemadi Glacier.
Note: Measurements for the Large Dongkemadi Glacier began before 1992, and thus the terminus location chart for this glacier does not begin at "zero."
Source: Yao, Wang, Liu, Pu, Shen, and Lu 2004.

2000 alone (Yao, Wang, Liu, Pu, Shen, and Lu 2004). The Large Dongkemadi Glacier began retreating in the summer of 1994, and its rate of retreat has also accelerated over time, reaching 4.56 m/year in 2001 (Yao, Wang, Liu, Pu, Shen, and Lu 2004). Wang and Zhang (1992) analyzed the relationship between global glacier fluctuations and climate change and found that the advance and retreat of mountain glaciers can lag a dozen years behind climatic changes. Thus, the advance of the Dongkemadi Glaciers in the early 1990s was the result of a period of climatic cooling in the 1970s, while the rapid retreat of these glaciers beginning in the mid-1990s is a response to the ongoing period of sustained climatic warming that began on the Qinghai-Tibet Plateau in the early 1980s (Pu, Yao, Wang, Su and Shen 2004).

Photo 3.8. Purog Kangri Ice Field, Nagchu Prefecture, TAR. File Photo: NASA-Johnson Space Center, Astronaut photography collection.

The Purog Kangri Ice Field, located just outside the Yangtze Source Region in the western Tanggula Range, is the largest ice field in the northern TAR (Photo 3.8). This ice field is composed of several adjoining ice caps and has an elevation range

of 5620-6482 m, a total glacier area of 422.6 km^2, and a total ice volume of 52.5 km^3 (Yao 1998; Pu, Yao, Wang, et al. 2002). The Purog Kangri Ice Caps themselves have more than 50 distinct glacier lobes of varying lengths that occupy wide, shallow valleys radiating out from these ice caps, the longest of which extends down to the foothills of the Purog Kangri massif. In historical times, the Purog Kangri Ice Field reached its maximum extent at the height of the Little Ice Age (LIA) during the 17th Century and has been experiencing a long period of nearly continuous retreat ever since. Between its LIA maximum and 2000, the total area of this ice field decreased by 24.20 km^2, a decline in area of about 5.7 percent from its maximum extent, or, in terms of volume, a loss of 3.66 km^3 of ice. Ice cover in the western Purog Kangri Ice Field typically retreated about 20 m between the field's LIA maximum and 1969, while from 1969-1999, glaciers in this ice field retreated a further 40-50 m. This represents an average rate retreat of about 1.3 to 1.7 m/year between 1969 and 1999, with an alarming 4-5 m of retreat occurring between September 1999 and October 2000 alone (Pu, Yao, Wang, et al. 2002).

Lu, et al. carried out a detailed study of glacial change on Geladandong Peak, analyzing satellite images, aerial photos, and topographic maps with remote sensing and GIS technologies to derive a digital elevation model (DEM) for the study site (Photo 3.9) (Lu, Yao, Liu et al. 2002). Through this process it was possible to determine the boundaries of the maximum LIA advance of the Geladandong Glaciers during the 17th Century and also the extent of subsequent changes to these glaciers from 1969-2000. The results of the study show that the total area of the Geladandong Glaciers decreased by about 5.2 percent between their maximum LIA advance and 1969, and decreased a further 1.7 percent between 1969 and 2000 with respect to their maximum LIA area (Table 3.8, Fig. 3.5). However, analysis of 70 individual glaciers in the Geladandong Ice Field revealed that, during the period from 1969-2000, six of these glaciers actually advanced, while 26 exhibited no significant change and the remaining 38 were all retreating. The maximum rate of advance of these glaciers was 21.9 m/year for Glacier 5K451F12, which grew by 680 m from 1969-2000, while the maximum rate of retreat measured in the study area was 41.5 m/year for the South Jianggendiru Glacier, which retreated a total of 1288 m from 1969-2000 (Table 3.9) (Lu, Yao, Liu et al. 2002). At the same time, the glacier in the study area experiencing the largest retreat as a percentage of its total length was Glacier 5K451F3, which lost 19.4 percent of its total length between 1966 and 2000, while Glacier 5K451F1 had the greatest advance as a

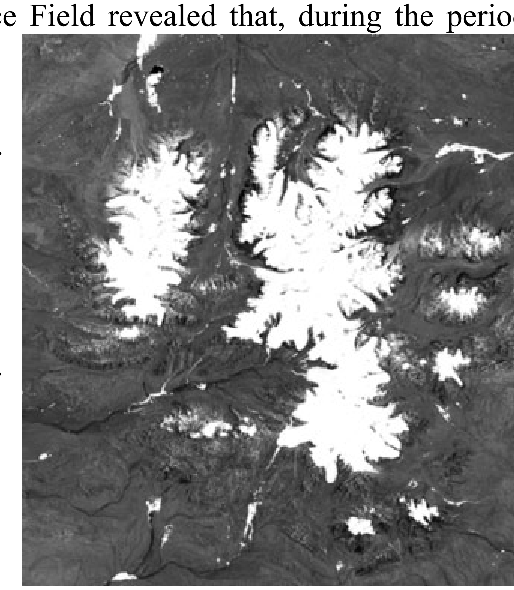

Photo 3.9. Geladandong (right) and Garkyagdeugang (left) Ice Fields, source of the Yangtze River, Tanggula District, Qinghai. NASA Landsat image.

percentage of its total length, increasing in total length by 49.4 percent (Table 3.9). It should be emphasized, however, that advancing glaciers are the exception in the Geladandong Ice Field, and that the number of retreating glaciers has been increasing since 1994 as temperatures in the region have risen. A glacier typical of the Geladandong Ice Field is the Jianggendiru Glacier, which retreated 24 m from 1970-2000, an average annual rate of retreat of 0.8 m/year (Lu, Yao, Liu et al. 2002).

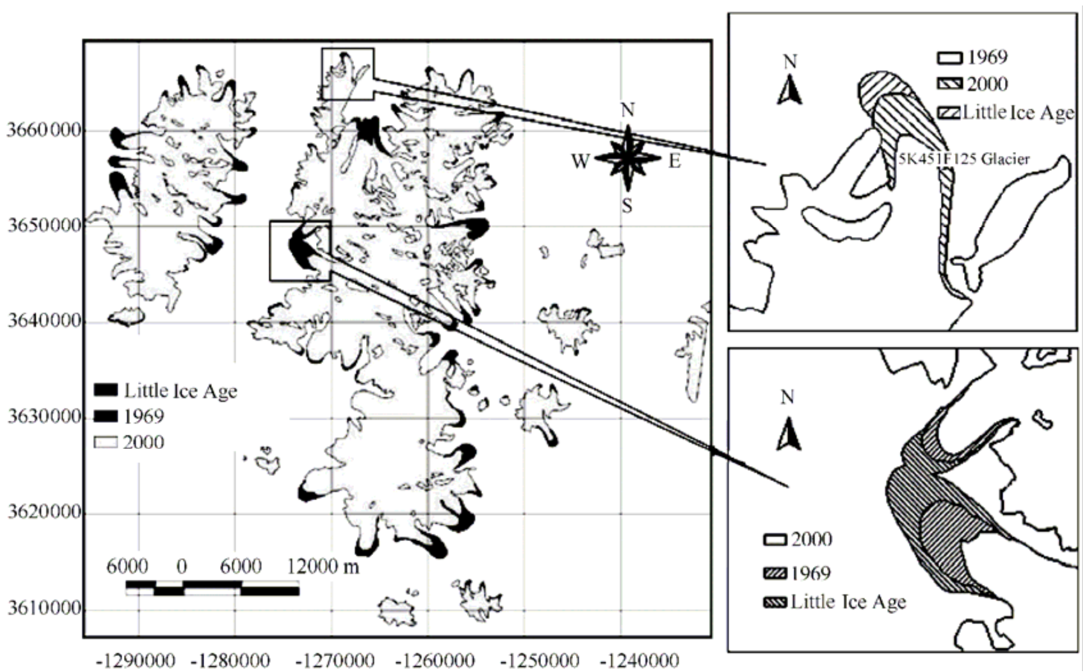

Figure 3.5. Retreat of the Geladandong (right) and Garkyagdeugang (left) Glaciers between their 17th Century Little Ice Age maximum advance and 2000.
Source: Lu, Yao, Liu et al. 2002.

Table 3.8. Changes in area of the Geladandong Glacier Fields, 17th Century to 2000

Year	Area of Glaciers (km^2)	Net Change (km^2)	Net Change (%)
Little Ice Age Maximum Advance (17th Century)	948.58	—	—
1969	899.31	- 49.27	-5.2%
2000	884.4	-14.91	-1.7%

Source: Lu, Yao, Liu et al. 2002.

Table 3.9. Maximum advance and retreat of the Geladandong Glaciers, Yangtze River Source, western Tanggula Range, Qinghai Province, 1969-2000

Glacier	Length in 2000 (m)	Advance or Retreat 1969-2000 (m)	Average Annual Advance or Retreat (m/yr)	Net Change in Length (%)	Notes
5K451F33 (South Jianggendiru Glacier)	12,400	-1288	-41.5	-10.4	Longest Total Retreat
5K451F3*	1200	-233	-6.9	-19.4	Longest Retreat as a Percentage of Total Length
5K451F12	5400	+680	+21.9	+12.6	Longest Total Advance
5K451F1	1100	+543	+17.5	+49.4	Longest Advance as a Percentage of Total Length

Source: Lu, Yao, Liu et al. 2002.
***Note:** Changes for this glacier are for the period from 1966-2000.

Table 3.10 Comparison of typical rates of glacier retreat in the Purog Kangri, Geladandong, and Malan Ice Fields, 1969-2000

Ice Field	Time Period (years)	Typical Total Retreat for Time Period (m)	Typical Rate of Retreat for Time Period (m/year)
Purog Kangri	1969-1999	40-50	1.3-1.7
Geladandong (including the Jianggendiru Glaciers)	1970-2000	24	0.8
Malan	1970-2000	30-50	1-1.7

By way of comparison, to the north, the glaciers of the Malan Ice Cap in the Hoh Xil Range retreated 30-50 m during the period from 1970-2000, with average annual rates of retreat of about 1-1.7 m/year (Table 3.10, Photo 3.7) (Pu, Yao, Wang, et al. 2001).

3.6.3 Glacier Mass Balances in the Yangtze Source Region

A study of glacier mass balances for the period from 1944-1993 showed that glaciers in the Yangtze Source Region had a combined negative mass balance, or net loss of ice, from 1944-1962 but a combined positive mass balance from 1963-1977, indicating a net gain of ice (Pu, Yao, and Zhang 1998). However, beginning in 1978, glacier mass balances in the Yangtze Source Region once again reverted to being negative, with one notable example being the Dongkemadi Glaciers, which had an exceptionally large combined negative mass balance from 1978-1993 (Table 3.11). During the 10-year period of maximum net ice loss, the mass balances of these glaciers ranged from -127 mm to -568 mm, or the equivalent of a lowering of

Table 3.11 Glacier mass balance of the Dongkemadi Glaciers, 1944-1995

Mass balance	Period			
	1944 – 1962	1963 – 1977	1978 – 1993	1991 – 1995
Total (mm)	-615.9	+2813	-1785	-695
Annual Mean (mm)	-32.4	+187.5	-111.6	-139

Source: Pu, Yao, and Zhang 1998.

ice surfaces by 160 to 670 mm (Pu, Yao, and Zhang 1998). During the period from 1991-1995, the combined mass balance of the Dongkemadi Glaciers decreased at an even faster rate, although most of this accelerated loss occurred from 1994-1995 (Table 3.11) (Pu, Yao, Wang, Su and Shen 2004).

3.6.4 Projected Fluctuations in Glaciers Accompanying Rising Temperatures in the Yangtze Source Region

A temperature sensitivity analysis of the Small Dongkemadi Glacier indicates that a 1ºC increase (or decrease) in annual mean temperature would lead to a decrease (or increase) of the glacier's mass balance by 686.4 mm and the raising (or lowering) of the glacier equilibrium line elevation by 219 m (Pu, Yao, and Zhang, 1996). Alternatively, a precipitation sensitivity analysis indicates that a 1 mm increase (or decrease) in precipitation during the cold season from October to May would result in an increase (or decrease) of the glacier's mass balance by 3.3 mm. Based on its location, topographic features, and its sensitivity to climate, in the event that precipitation remains constant and the annual mean temperature at the glacier increases by 1ºC, the Small Dongkemadi Glacier will retreat by 1.74 km, while in contrast, a drop in annual mean temperature of 1ºC would result in an advance of the glacier by 5.31 km (Wang, Yao, and Pu 1996). For an increase in annual mean temperature of 1.7ºC, it is believed that the Small Dongkemadi Glacier will disappear entirely (Shen, Wang, and Wu 2002).

Zhao et al. have predicted that the temperature in the Yangtze Source Region will increase 3ºC by 2100 (Zhao, Gao, Tang, et al. 2002). In the event of such a temperature increase occurring, in the absence of an increase in precipitation most glaciers less than 4 km in length in the Yangtze Source Region will disappear entirely, resulting in a decrease of 60 percent or more in the total area of glacier cover in the region. Glaciers that would remain under this climate scenario would be largely restricted to the Tanggula Range along the southern boundaries of the Tuotuo and Dam Chu River basins (Wang, Yao, and Pu 1996). In the event of a 40 mm, or 20 percent, increase in winter precipitation in the Yangtze Source Region, average glacial mass balance in the region will increase by 120 mm, which would offset the increased rate of glacial meltoff caused by a 3ºC increase in temperature (Wang, Yao, and Pu 1996).

However, increasing air temperatures also affect the distribution and duration of seasonal and perennial snowfall on the Qinghai-Tibet Plateau, as well the timing of

seasonal snowfall. Thus it has been projected that future increases in temperatures on the plateau will lead to increases in both the amount of snowfall and duration of snow cover in the Yangtze Source Region (Shen, Wang, and Wu 2002). Consequently, based on the type and size of glaciers in the Yangtze Source Region and on the feedback effects of changes in snow cover, if the rate of warming is limited to 0.03ºC/year, it is estimated that total annual precipitation in the region will increase by 10 percent per 1ºC of warming, or by about 10 percent every 33 years (Shen, Wang, and Wu 2002). Although significant, an increase in precipitation of this magnitude will by no means be sufficient to compensate for the accelerated melting of glacial ice resulting from this rate of temperature increase. Consequently, it is projected that under this scenario of simultaneous increases in temperatures and precipitation, the total area of glacier cover in the Yangtze Source Region will decrease by 35-40 percent by 2100, falling from the 1969 total of 1168 km^2 to about 700 km^2 by 2100 (Shen, Wang, and Wu 2002).

Thus, under conditions of rising temperatures, it is anticipated that the extent of glacier cover in the Yangtze Source Region will decline dramatically in coming decades, which in the future will have large negative impacts on the volumes of both surface runoff and ground water recharge in the region. Unfortunately, the total area of glacier cover in the Yangtze Source Region decreased by 1.87 km^2 during the period from 1992-1997 alone (Lu, Yao, Liu, et al. 2002). Assuming an average retreat of 8.5 m and a lowering of ice surfaces by 487 mm for glaciers in the Yangtze Source Region during this period, this decline in area represents a loss of an estimated 700 million m^3 of glacial water resources (Lu, Yao, Liu, et al. 2002). Further large-scale decreases in the region's glacier cover will severely affect the availability of water resources in the region, which will affect both the region's ecosystems and its human inhabitants.

3.7 Hydrology of Glacial Meltwater in the Yangtze Source Region

3.7.1 <u>A Model for Estimating Annual Net Glacier Mass Balances in Western China</u>

In the high mountain valleys of western China, temporal changes in glacier mass balances occur in a fairly predictable pattern. After studying the local hydrological and climatic aspects of western China's glaciers, including those found in the Tian Shan, Pamir, and Altai Ranges, Shen et al. have found that the precipitation distribution in a given drainage basin follows the principle of maximum entropy, with there being a negative exponential relationship between maximum precipitation in a basin, P_{max}, and the corresponding area of maximum precipitation of a drainage basin, S_{max}:

$$S_{max} = S \exp[-(P_{max} - P_0)/(P - P_0)] \qquad (3.1)$$

where S is the area of the entire drainage basin, P is the drainage basin's annual mean precipitation, and P_0 is the minimum annual precipitation of the basin (Shen, Xie, Ding, et al. 1997). It is possible to estimate the average annual net glacier mass balance for all glaciers in a given drainage basin using local precipitation measurements. Shen et al. have suggested that in the mountainous regions of China's west, the runoff yield and runoff coefficient have the same relationship as shown in Equation (3.1) (Shen, Xie, Ding, et al. 1997).

In investigating the alpine and plateau regions of China's west, it was discovered that the maximum precipitation centers of drainage basins with glacier cover occur on the glacier surface itself, as glacier surfaces are cold and enhance cloud formation, making the glacier surface the basin's maximum precipitation area. Consequently, a drainage basin's glacier surfaces are also its maximum runoff yield areas and its maximum runoff coefficient areas as well. Hence, it follows that $S_g = S_{max}$, where S_g is the total glacier area of a drainage basin. Given these relationships between glacier cover, precipitation, and runoff, Shen, et al. (1997) have put forward the following equations to model the precipitation, runoff yield, and runoff coefficient for drainage basins with glacier cover:

$$P_g = P - (P - P_0)\ln(S_g/S) \tag{3.2}$$

$$R_g = R - (R - R_0)\ln(S_g/S) \tag{3.3}$$

$$\alpha_g = \alpha - (\alpha - \alpha_0)\ \ln(S_g/S) \tag{3.4}$$

where P_g, R_g, and α_g are the annual mean precipitation, annual mean runoff depth, and annual mean runoff coefficient for glacier covered areas of a drainage basin, respectively; P, R, and α represent the annual mean precipitation, annual mean runoff depth, and annual mean runoff coefficient for the entire drainage basin, respectively; and P_0, R_0, and α_0 are the minimum annual precipitation, minimum annual runoff depth, and minimum annual runoff coefficient of the entire drainage basin respectively.

The ratio of annual mean runoff depth in a drainage basin to the annual mean runoff depth from glaciers in the basin, K_{GR}, can be estimated for drainages with river gages and meteorological stations according to the water balance principle as follows:

$$K_{GR} = (S_g/S)\{1 + [\ \alpha_B(SP - S_gP_g) - (SR - S_gR_g)]/(S_gR_g)\} \tag{3.5}$$

where α_B is the runoff coefficient of bare slopes, which can be estimated as follows:

$$\alpha_B = (\alpha_S - \alpha_gS_g)/(S - S_g) \tag{3.6}$$

In the same manner, the ratio between the annual mean precipitation at a meteorological station in a given drainage basin and the annual mean precipitation on glaciers in that basin, K_{GP}, is simply estimated as:

$$K_{GP} = P_s/P_g \qquad (3.7)$$

where P_s is the annual mean precipitation for a given meteorological station.

According to the principles of glacier mass balance, the net glacier mass balance of a drainage basin in any given year can be estimated as:

$$B_{ni} = C_i - A_i \qquad (3.8)$$

where B_{ni} is the net glacier mass balance of a given drainage basin in year “i”, C_i is the annual accumulation depth on the basin’s glaciers in year i, and A_i is the annual ablation from the basin’s glaciers in year i. C_i and A_i can be estimated as follows:

$$C_i = P_{si}/K_{GP} \qquad (3.9)$$

where P_{si} is the precipitation at a given meteorological station in the basin in year i, and

$$A_i = R_i/K_{GR} \qquad (3.10)$$

where R_i is the given basin’s runoff depth in year i.

Based on Formulas 3.2-3.10 and runoff and precipitation data collected at river gages and meteorological stations in the Yangtze Source Region from 1961-2000, it is possible to estimate annual series for various glacier mass balance parameters in the region’s drainage basins. For the example analysis that follows, we have chosen the Yanshiping Station on the Bi Chu River, the Tuotuo River Station, and the Chumda Station on the lower Tongtian River for our calculations, all of which have continuous precipitation and river flow records dating back to 1961. Precipitation and river flow data from these stations provides an excellent record of climatic change over the past five decades in the Yangtze Source Region and also provides a scientifically sound basis on which to estimate other aspects of glacial change in the region’s drainage basins. The results of these calculations are given in Table 3.12, below.

Table 3.12 Annual mean values for various hydrological and glacial parameters in the Bi Chu, Tuotuo, and Tongtian River Basins of the Yangtze Source Region, 1961-2000

River Basin Parameter	Bi Chu River	Tuotuo River	Tongtian River (Entire Yangtze Source Region)
Meteorological/River Gage Station	Yanshiping	Tuotuo River	Chumda
Precipitation and Runoff Data Collection Period	1961-2000	1961-2000	1961-2000
Total Watershed Drainage Area above Station, S (km^2)	4248	15,924	137,704
Total Surface Area of Glacier Cover in a given Watershed, S_g, in 1969 (km^2)	195.7	385.3	1168
Annual Mean Runoff Depth, R (mm)	187.7	51	88.7
Annual Mean Precipitation, P (mm)	470	340	390
Annual Mean Runoff Coefficient, α	0.4	0.15	0.23
Minimum Annual Runoff Depth, R_0 (mm)	150	5	5
Minimum Annual Precipitation, P_0 (mm)	350	200	240
Minimum Annual Runoff Coefficient, α_0	0.15	0.05	0.10
Annual Mean Runoff Depth from Glaciers, R_g (mm)	700	480	510
Annual Mean Precipitation on Glaciers, P_g (mm)	1100	900	937
Annual Mean Runoff Coefficient for Glaciers, α_g	1.4	No Data	1.3
Ratio of Drainage to Glacier Annual Mean Runoff, K_{GR}	0.18	0.06	0.096
Ratio of Station to Glacier Annual Mean Precipitation, K_{GP}	0.34	0.416	0.40
Glacier Accumulation Depth, C (mm)	1042	900	937
Glacier Ablation, A (mm)	1100	850	924
Glacier Mass Balance (mm)	1070	875	931
Net Glacier Mass Balance, B_n (mm)	60	50	13
Contribution of Glacial Meltwater to Total River Flow (%)	18	22	9

Source: Precipitation and runoff data provided by Qinghai Hydrological and Water Resource Bureau, other data based on original calculations by Yongping Shen.

3.7.2 Contribution of Glacial Meltwater to Total River Flow in the Yangtze Source Region

The Chumda River Gage Station on the lower Tongtian River recorded an annual mean runoff volume of 12.52 billion m^3 for the period from 1961-2000, of which 13 percent is contributed by the combined flow of the Tuotuo and Garchu Rivers, 2 percent by the Chumar River, 6 percent by the Bi Chu River, and 15 percent by the Dam Chu River (Table 3.13). The remaining 64 percent of flow passing the Chumda Station originates along the lower reaches of the Tongtian River downstream of its junction with the Chumar River. Estimates of the contribution of glacial meltwater to total river flow for the major rivers in the Yangtze Source

Table 3.13 Glacial meltwater as a percentage of total river flow in the Yangtze Source Region.

River	Contribution of Selected Tributaries to the Total Annual Flow of the Tongtian River at the Chumda River Gage Station (%)	Contribution of Glacial Meltwater to Total Annual Flow for Selected Tributaries (%)
Tuotuo and Gar Chu Rivers (Combined)	13	22
Chumar River	2	No Data
Bi Chu River	6	18
Dam Chu River	15	20
Lower Reaches of the Tongtian River	64	No Data
Total at the Chumda Station	100	9

Source: Original calculations by Yongping Shen.

Region have been made based on the glacier mass balance model for western China detailed in section 3.7.1, above. Using this model, glacial meltwater is estimated to account for about 22 percent of the combined total annual flow of the Tuotuo and Gar Chu Rivers, 20 percent of the total annual flow of the Dam Chu River, and 18 percent of the total annual flow of the Bi Chu River (Table 3.13). In total, glacial meltwater is estimated to account for about 9 percent of all surface flow in the Yangtze Source Region each year as measured at the Chumda River Gage Station, or an average of about 1.13 billion m^3 of water per year over the period from 1961-2000 (Table 3.13).

With there presently being such a large number of glaciers in the Yangtze Source Region, it is not surprising that glacial meltwater makes up a significant percentage of the region's stream flow and plays a critical role in regulating river flow throughout the region. Glacial meltwater is particularly important for regulating the flow of rivers in the upper part of the Yangtze Source Region. Apart from the Chumar and Beilu Rivers, which are primarily fed by rainfall, the other major rivers of the upper Yangtze Source Region, specifically the Tuotuo, Dam Chu, Gar Chu, and Bi Chu Rivers, are all fed by large glaciers in the Tanggula Range, and glacial meltwater forms a large percentage of their total annual flows (Table 3.13). The glaciers of the Yangtze Source Region are typical continental-type glaciers, having a short period of ablation from May to September. Consequently, most glacial meltwater flow occurs from June-August, which happens to coincide with the peak of rainy season in the region, with the result being that 90 percent of the Tongtian River's total annual flow occurs in summer and early fall. A minor amount of snow and glacial meltwater flow begins to occur in March, but this flow does not become significant until late April. However, summer flooding begins in June as warmer temperatures lead to a rapid rise in the volume of glacial meltwater flow, which combined with the onset of rainy season results in the seasonal swelling of the Yangtze Source Region's rivers.

The annual flow of glacial meltwater generally peaks in July, consequently the total annual flow of glacial meltwater is highly dependent on July temperatures in any given year, with glacial meltwater flow in August even being largely determined by July temperatures. Thus, the close correlation between July temperatures and river flow in the Yangtze Source Region illustrates the importance of glacial meltwater in the annual flow cycle of the region's rivers. For example, at the Tuotuo River Gage Station, temperature is the primary factor determining the total volume of river flow from June-September, during which time temperature is even more important than precipitation as, in general, the Tuotuo River basin receives very little precipitation. The combination of these factors results in glacial meltwater accounting for 22 percent of the Tuotuo River's total annual flow, with the other 78 percent of flow in the river being derived from rainfall, snowmelt, groundwater, and meltwater from seasonally frozen ground and permafrost. Since glacial meltwater accounts for such a large percentage of the total river flow in the Yangtze Source Region, the distribution of surface flow in the region throughout the course of the year is extremely uneven.

An examination of temperature and surface flow for the 1961-2000 period shows that the annual melting period for glacial ice, snow, and frozen ground in the Yangtze Source Region now begins earlier due to increases in spring temperatures over the past few decades. One result of this earlier onset of the thaw period is that peak annual runoff rates during summer flood season have been reduced, as the peak of the annual meltoff is now occurring earlier, while the mid-summer peak of annual precipitation remains unchanged. A second result of rising temperatures in recent decades is that, since 1993, glaciers in the Yangtze Source Region have been experiencing a long period of rapid ablation, and consequently annual volumes of glacial meltwater runoff in the region are estimated by the author to have increased by 250 to 300 million m^3 in the period from 1994-2005. At the same time, increased rates of glacier ablation have resulted in an even more uneven distribution of annual runoff in the Yangtze Source Region, although interannual variability in total annual runoff volumes in the region has grown smaller

3.8 Future Impacts of Climate Change on Yangtze Source Region Glaciers

Over the 40 year period from 1961-2000, climate change in the Yangtze Source Region has been characterized by increases in both temperature and precipitation, with the most dramatic changes having occurred since the mid- to late 1980s. Since the onset of rapid warming in the 1970s, the annual mean temperature in the region has increased by 0.8ºC, while precipitation in both spring and winter has also increased significantly (Yang, Ding, Shen, Liu and Chen 2004). Previous studies have shown that mountain glaciers in the Yangtze and Yellow River Source Regions are extremely sensitive to increases in temperature resulting from climate change. However, changes in precipitation resulting from climate change have also

had a significant impact on the region's glaciers (Shen, Wang, and Wu 2002). In the sections that follow, glacial parameters for the Yangtze Source Region and a model for predicting the response of the region's glaciers to climate change are presented, as are predictions obtained from this model under several different scenarios of climatic change.

3.8.1 Basic Parameters for Modelling Glaciers in the Yangtze Source Region

In order to model the response of glaciers in the Yangtze Source Region to climate change, basic data about the region's glaciers is needed. Wang, et al. compiled basic data on glacial parameters for ice fields in the Yangtze Source Region, such as total area, total volume, number of glaciers, etc., from the *Glacier Inventory of China* and the *Concise Book of China Glaciers Inventory*, which are based on aerial surveys conducted in 1969. Atmospheric temperature data for the Yangtze Source Region was obtained from the climate section of the *Atlas of the Qinghai-Tibet Plateau*, which is based on 1970s meteorological data (Wang, Xie,

Table 3.14 Basic parameters for glaciers in the Yangtze Source Region and adjacent ice fields normalized to 1970

Parameter	Location (Mountain Range)			
	Sederi Peak* Xiqiaorisheng (combined)	Tanggula Range Zurhen Ul Dongbuli Range Ulan Ul (combined)	Kunlun Range (Yuzhu Peak)	Yangtze Source Region and South Sederi Peak (combined)
Number of Glaciers, N	146	560	47	753
Glacier Area, S_0 (km^2)	121.17	1107.76	47.09	1276.02
Glacier Volume, V_0 (km^3)	6.671	95.33	2.41	104.41
Equilibrium Line Altitude during Steady-state Periods, ELA_0 (m)	5335	5537	5321	5497
Median Area of Glaciers, S_{med} (km^2)	1.61	5.1	1.23	4.22
Accumulation Area Ratio, AAR	0.61	0.75	0.76	0.75
Mean Summer Temperature at the Steady-state Equilibrium Line, t_s (°C)	+0.25	-0.79	-1.03	-0.86
Initial Rainfall for Glacier Surfaces, P_0 (mm)	643	468	433	458

***Note:** Only 18 of the glaciers on or in the vicinity of Sederi Peak actually lie in the Yangtze Source Region. The remaining 126 of the Sederi Peak Glaciers lie south of the Yangtze watershed divide inside the Mekong Source Region.
Source: Wang, Xie, Feng, Yang, Yang, and Lin 2005.

Feng, Yang, Yang, and Lin 2005; Pu 1994; Shi, Liu, Wang 2005; Institute of Geography 1990). In order to create a reference period for this data, all parameter values were normalized to 1970 (Table 3.14) (Wang, Xie, Feng, Yang, Yang, and Lin 2005).

3.8.2 Modified Model for Estimating Changes in Glacier Area in Response to Climate Change

In order to predict the response of Yangtze Source Region glaciers to climate change, the glacier system variation model proposed by Xie, et al. was modified to enable the glacier mass balance at a glacier's equilibrium line altitude to represent the average mass balance of the entire glacier (Xie, Ding, Liu, and Liu 1996; Xie, Han, Liu, and Liu 1999). This was achieved by substituting the altitude of a glacier equilibrium line occurring under relatively stable conditions for the actual steady-state equilibrium line altitude of a glacier (Xie, Wang, and Kang 2006; and Xie, Feng, and Liu 2002). At the glacier equilibrium line, glacial accumulation is equal to glacial ablation, with glacial meltoff being primarily dependent on summer temperatures (Xie, Ding, Liu, and Liu 1996). Under non-steady-state conditions, the mass balance of glacier "n", b_n, at the steady-state equilibrium line (ELA_0), $b_n(ELA_0) = 0$, is continuously fluctuating, although the mass balance at the steady-state equilibrium altitude remains equal to the net mass balance of the entire glacier,

$$b_n(\mathrm{ELA}_{0\mathrm{i}}) = \overline{b_{ni}} \tag{3.11}$$

where $b_n(ELA_{0i})$ is the net mass balance of the glacier at the glacier's relative steady-state equilibrium line altitude, ELA_{0i}, in year "i", and is the net mass balance of the entire glacier "n" in year i.

Under conditions of climatic change, one can work out the specific net mass balance of a glacier in year i, $\overline{b_{ni}}$, based on the net mass balance at the steady-state equilibrium line altitude in year i using the following regression equation derived by Xie et al.:

$$\overline{b_{ni}} = 1.33[(9.66 + t_s)^{2.85} - (9.66 + t_s + \Delta t_{si})^{2.85}] + \Delta p_i \tag{3.12}$$

where ts is the mean summer temperature at the steady-state equilibrium line altitude, ELA_0, Δt_{si} is the difference between the mean summer temperature at ELA_0 and the mean summer temperature at ELA_{0i}, and Δp_i is the difference in solid precipitation accumulation between ELA_0 and ELA_{0i} (Xie, Feng, and Liu 2002).

The ratio between the absolute value of net mass balance of a glacier in year i, $\left|\overline{b_{ni}}\right|$, and net ablation in year i, $\overline{a_i}$, γ_i is:

$$\gamma_i = \frac{\left|\overline{b_{ni}}\right|}{\overline{a_i}} \tag{3.13}$$

In any given year i, runoff from a glacier will initially be low, increase with the onset of summer, and then fall back to its initial level the following winter. Without taking evaporation into account, the runoff depth from a glacier in year i, r_i, will equal net ablation from the glacier in the given year, $r_i = \overline{a_i}$, while the runoff depth from the retreated area of a glacier, r_d, will equal the absolute value of net mass balance of the entire glacier "n" in year i, $r_d = \left|\overline{b_{ni}}\right|$. Using the value for the ratio γ_i, obtained above, the area of glacial retreat in year i, s_d, can then be estimated as:

$$s_d = \frac{s_i \gamma_i}{\gamma_i + 1} \tag{3.14}$$

where s_i is the maximum area of a glacier in year i prior to retreat.

Based on the relationship between the average area and thickness of a glacier, the time for reaching the restored state of a glacier (the return to the annual maximum area of a glacier following summer ablation and retreat) in year i, T_{ei}, is:

$$T_{ei} = \frac{1.8(\gamma_i + 1)}{\left|\overline{b_{ni}}\right|(\gamma_i + 2)}\{53.21 s_i^{0.3}[1 - (\frac{1}{\gamma_i + 1})^{1.3}] - 11.32\gamma_i\} \tag{3.15}$$

and the maximum area of a glacier in a given year i, s_i, can be estimated as:

$$s_i = s_{i-1}(1 - \frac{\gamma_i}{(1+\gamma_i)T_{ei}}) \tag{3.16}$$

With the temperature in the Yangtze Source Region increasing at a rate of 0.2ºC/decade during the period from 1961-2000, studies predict that by 2050 the temperature of the region may be 2.3-2.7ºC higher than the annual mean for the 1961-1990 reference period, with the rate of warming potentially reaching 0.25-0.35ºC/decade (Yang, Ding, Shen, Liu, and Chen 2004; Zhao, Gao, Tang, et al. 2002). Based on the HadCM2 model of the U.K. Hadley Center for Climate Prediction and Research, Wu et al. predicted that each 1ºC of warming in the Yangtze Source Region will be accompanied by a 22.9 mm increase in annual precipitation (Wu, Yu, and Xu 2001).

Thus, taking the present rate of warming in the Yangtze Source Region of about 0.2ºC/decade and Wu et al.'s predicted increase in precipitation of 22.9 mm per 1ºC of warming, the modified glacier fluctuation model discussed above has been used

Table 3.15 Predicted response of glaciers to climate change in the Yangtze Source Region up to the year 2050 at the present rate of warming in the region of 0.2 ºC/decade.

Ice Field	Change in Total Glacier Area, $\Delta S/S_0$ (%)			Change in Annual Mean Glacier Meltwater Flow Rate, $\Delta W/W_0$ (%)			Change in Steady-state Equilibrium Line Altitude, ΔELA_0 (m)		
	2010	2030	2050	2010	2030	2050	2010	2030	2050
Sederi Peak	-5.3	-11.2	-18.8	+15.4	+17.1	+14.8	+12.4	+26.1	+43.6
Tanggula Range (North Slope)	-3	-6.3	-10.7	+20.5	+26.7	+30.1	+13.8	+28.8	+47.5
Kunlun Range (South Slope)	-4.6	-9.7	-16.1	+19	+22.6	+22.4	+14.6	+30.7	+51.2
Entire Yangtze Source Region	-3.2	-6.9	-11.6	+20.4	+26	+28.5	+13.9	+29.6	+49.6

Note: ΔS is the change in glacier surface area, S_0 is the glacier surface area in 1970, ΔW is the change in annual mean glacial meltwater flow rate, and W_0 is the annual mean glacial meltwater flow rate in 1970.
Source: Wang, Xie, Feng, Yang, Yang, and Lin 2005.

to estimate the extent of future glacier fluctuations in the Yangtze Source Region for the period from 2001-2050. Yangtze Source Region glacial parameters normalized to 1970, summarized in Table 3.14, have been selected as the starting point of this analysis, which again examines the response of glaciers to different climate warming scenarios with respect to changes in total glacier area, glacier meltwater flow rates, and altitude of glacier steady-state equilibrium lines. The results of this analysis are summarized in Table 3.15 where it can be seen that, in terms of their response to changes in climate, there are some major differences between the three main glacier areas of the Yangtze Source Region. With respect to the total area of glacial retreat, the ice fields of the northern slope of the Tanggula Range had the slowest rate of decrease in area of glacier cover while the Sederi Peak Ice Fields had the fastest rate, with the Kunlun Range glaciers being intermediate between the two. This may indicate that the overall rate of change in total glacier area on the Qinghai-Tibet Plateau will be less pronounced in the interior of the plateau than along the outer edges.

In terms of the Yangtze Source Region as a whole, at the present rate of warming of 0.2ºC/decade and a projected increase in annual mean precipitation of 22.9 mm per 1ºC of warming, the model predicts that the glaciers of the Yangtze Source Region will have the following collective response to this climate change scenario:

- The total area of glacier cover in the Yangtze Source Region will decrease by about 3.2 percent by 2010, 6.9 percent by 2030, and 11.6 percent by 2050 with respect to the 1970 value.

- The annual mean flow rate of glacier meltwater in the Yangtze Source Region will increase by 20.4 percent by 2010, 26 percent by 2030, and 28.5 percent by 2050 with respect to 1970.

- The mean altitude of glacier steady-state equilibrium lines in the Yangtze Source Region will increase by about 13.9 m by 2010, 29.6 m by 2030, and 49.6 m by 2050 with respect to 1970.

Although the global mean surface air temperature is expected to continue to rise throughout this century, as is the mean surface air temperature on the Qinghai-Tibet Plateau, any attempt to predict the future rate of climate warming is fraught with uncertainty. As discussed above, by one estimate the rate of warming on the plateau may increase from the present 0.2ºC/decade to 0.25-0.35ºC/decade by 2050. Given this high degree of uncertainty concerning the future rate of warming, the impacts of three additional rates of warming on the glaciers of the Yangtze Source Region for the period up to 2050 are examined here, specifically for future rates of warming of 0.1ºC/decade, 0.3ºC/decade and 0.5ºC/decade. These warming rates have been chosen based on the prediction of Xie et al. that the rate of climate warming in the 21st Century will be confined to a range of 0.1-0.5ºC/decade (Xie, Feng, and Liu 2002). Figure 3.6 shows the predicted changes in features of the Yangtze Source Region's ice fields up to 2050 based on these three rates of warming and Wu's predicted increase in annual mean precipitation of 22.9 mm per 1ºC of warming.

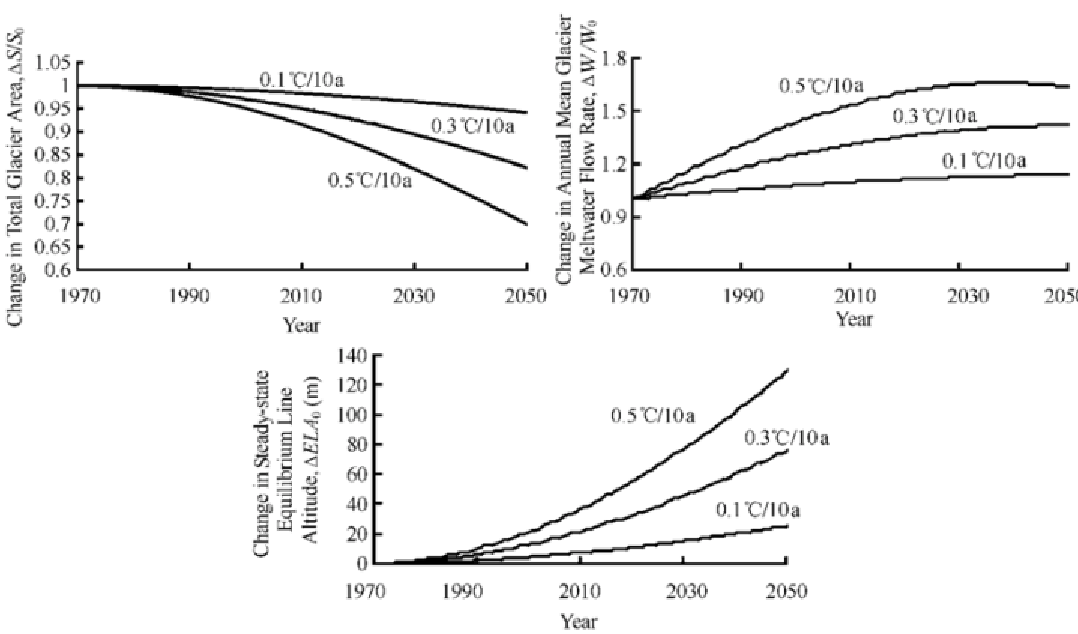

Figure 3.6. Predicted average response of all glaciers in the Yangtze Source Region to three different rates of climate warming, 1970-2050.
Source: Wang, Xie, Feng, Yang, Yang, and Lin 2005.

Taking the intermediate rate of warming of 0.3ºC/decade, it can be seen that changes in the modeled features of glaciers in the Yangtze Source Region are dramatically larger than for the present rate of warming of 0.2ºC/decade. Under this climate warming scenario, the model predicts that the glaciers of the Yangtze Source Region will have the following collective response:

- The total area of glacier cover in the Yangtze Source Region will decrease by about 5 percent by 2010, 10 percent by 2030, and 20 percent by 2050 with respect to the 1970 value.

- The annual mean flow rate of glacier meltwater in the Yangtze Source Region will increase by 32 percent by 2010, 39 percent by 2030, and 43 percent by 2050 with respect to 1970.

- The mean altitude of glacier steady state equilibrium lines in the Yangtze Source Region will increase by about 22 m by 2010, 47 m by 2030, and 75 m by 2050 with respect to 1970.

3.9 Conclusions

The annual mean runoff volume of the Yangtze Source Region as measured at the Chumda River Gage Station presently only accounts for about one percent of the entire Yangtze River's total annual flow volume (e.g. see Zhou, Goel, and Bhatt 2002). Although this is only a small fraction of the Yangtze Basin's entire flow, the extensive rivers, lakes, wetlands, glaciers, snowfields, and permafrost of the Yangtze Source Region, as well as the region's vast alpine grasslands, play a critical role in storing and regulating the flow of water in the entire upper Yangtze watershed of Qinghai, the TAR, Yunnan, and western Sichuan. However, in the 1990s, in addition to rising temperatures, a period of increasing aridity began in the Yangtze Source Region which has severely affected the region's surface water resources, leading to the drying up of numerous lakes, ponds, marshes, and bogs in the region (Wang, Ding, Wang, and Liu 2004). This drying up of lakes and wetlands has been followed by desertification, with shifting sand dunes appearing where none had been present before, particularly in areas along the Chumar and Tongtian River corridors that were formerly marshes (Wang, Ding, Wang, and Liu 2004).

In addition to causing the drying up of wetlands and desertification, climate change is also the dominant factor in the recent rapid decline in the volume of the Yangtze Source Region's glacier resources. For example, studies of the Dongkemadi Glaciers in the Tanggula Pass area of the Yangtze Source Region have shown that these glaciers have been retreating rapidly since the mid-1990s, producing a total volume of about 250-300 million m^3 of glacial meltwater between

1993 and 2005. And it is predicted that at the current rate of warming of 0.02ºC/year, the total area of glacier cover in the Yangtze Source Region will decrease by 11.6 percent by 2050 with respect to total area of these ice fields in 1970. As a critical source of surface water on the eastern Qinghai-Tibet Plateau and beyond, the mass retreat of glaciers in the Yangtze Source Region will have an enormous negative impact on livestock herding and farming activities in the upper Yangtze watershed as well as on the viability of present ecosystems and even socioeconomic development in the upper Yangtze Basin. Thus, in order to protect the water resources and ecosystems of the Yangtze Source Region long into the future, more emphasis will need to be placed on countering the tremendous negative impact climate change is already having on the region, which will only grow in magnitude in coming decades.

Chapter Acknowledgements

This work was supported in part by the Major State Basic Research Development Program of China (973 Program, Grant No. 2007 CB411507) and the National Natural Science Foundation of China (Grant No. 40771047).

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Changes in Permafrost along the Qinghai-Tibet Highway in the Yangtze Source Region

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4.1 Introduction

Frozen ground is classified into three broad categories by the length of time that soil is frozen: 1) "temporarily frozen ground" is ground that is frozen for 15 days or less, 2) "seasonally frozen ground" is ground that is frozen for periods from 15 days up to one year, and 3) "permafrost," which is defined on the basis of temperature as soil or rock at a depth below the earth's surface which remains below 0ºC for two years or more (Washburn, 1979). As a result of the combined effects of climate, geography, geology, hydrology, and vegetation, permafrost is itself a separate geologic entity formed by the exchange of mass and energy between the earth and atmosphere and has its own unique evolutionary history (Zhao, Chen, Cheng, and Li, 2000).

Likewise, permafrost on the Qinghai-Tibet Plateau has a unique natural history, with the region's unusual combination of extreme elevation and harsh climatic conditions having produced the highest and largest permafrost region at lower and middle latitudes on earth (Fig. 4.1). The permafrost zones of the Qinghai-Tibet Plateau have a total area of 1,401,000 km^2, or 54.3 percent of the plateau's total area, with seasonally frozen ground distributed over much of the rest of the region (Li, Cheng, and Zhou, 1996). This includes nearly all of the Yangtze Source Region where an extensive zone of continuous permafrost occurs between the Kunlun and Tanggula Ranges (Photos 3.2 and 4.1) (Li, Cheng, and Zhou, 1996). However, monitoring results have

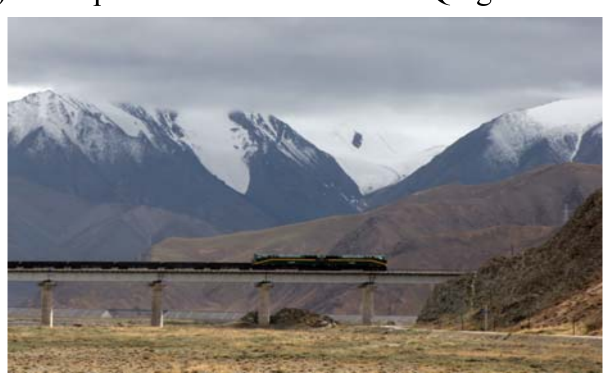

Photo 4.1. Qinghai-Tibet Railroad, Kunlun Range, Golmud Municipality, Qinghai. Photo by Dawa Tsering.

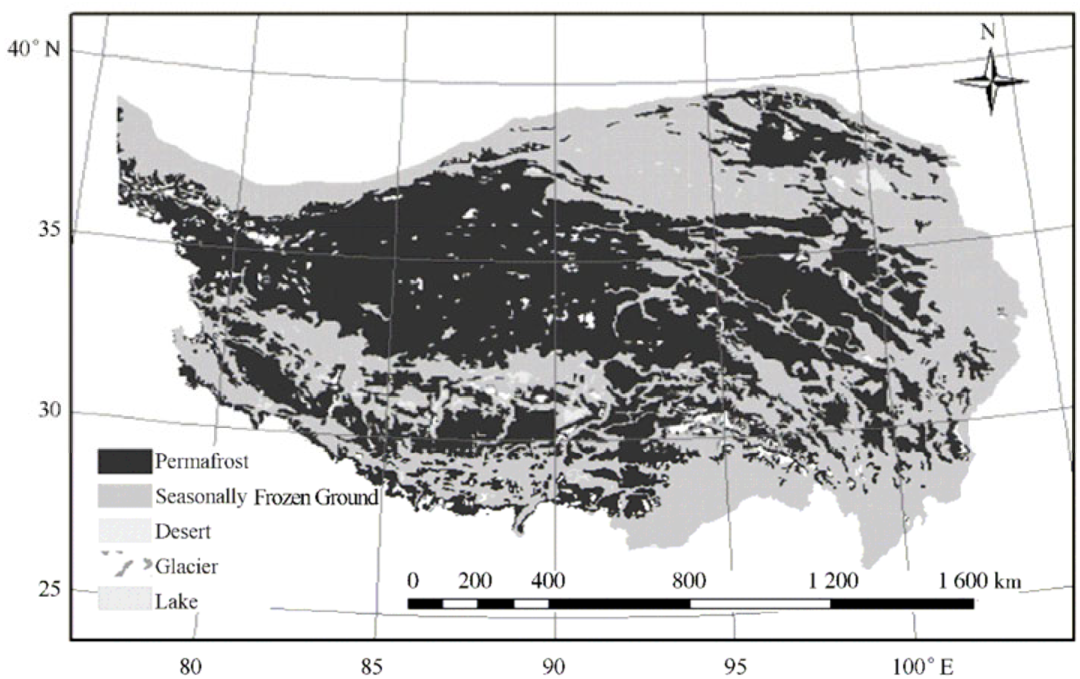

Figure 4.1. Distribution of permafrost on the Qinghai-Tibet Plateau.
Source: Li, Cheng, and Zhou 1996.

shown that over the past several decades, permafrost on the Qinghai-Tibet Plateau has experienced a continuous decline which continues to this day.

With increases in the thickness of permafrost active layers on the Qinghai-Tibet Plateau, the fundamental properties of soils, such as water content and temperature, have changed in the plateau's permafrost areas. As a consequence, the types and patterns of vegetation that local active layers can support have also undergone corresponding changes. Therefore, it is important to study ecological degradation of vegetation on the Qinghai-Tibet Plateau in the context of changes in permafrost as well as in relation to changes in atmospheric temperature, precipitation, and land use.

4.2 Distribution of Permafrost on the Qinghai-Tibet Plateau

Average temperatures on the Qinghai-Tibet Plateau decrease towards the north and east of the plateau as well as with increasing elevation. Consequently, climatic conditions that are a function of elevation and latitude, and to a certain degree longitude, are the determining factors that control the distribution of permafrost on the Qinghai-Tibet Plateau. As a result, the lowest altitudinal limit of permafrost occurs in the north and east of the plateau, while in the south of the plateau the altitudinal limit of permafrost occurs at elevations on the order of 500-1000 m higher than on the northern plateau (Table 4.1). Thus, variation in the altitudinal

Table 4.1 Distribution of permafrost on the Qinghai-Tibet Plateau.

Permafrost Region	Altitudinal Limit of Permafrost (m)	Area (x 10^3 km^2)	Percentage of Region Underlain by Perma-frost (%)	Depth of Permafrost below the Ground Surface (m)	Annual Mean Surface Temperature (°C)
Mountains of Southeast Qinghai Province	3840-4300	181.9	63	Several to 70	-0.5 to -3.2
Kunlun Range, Northern TAR and Central Qinghai Province	4000-4200	75.7	63	4-100	0 to -3.2
Karakorum and West Kunlun Ranges, Western Qinghai-Tibet Plateau	4200-4600	135.9	67	4-120	-0.1 to -3.2
Chang Tang Plateau, Northern TAR and Southwest Qinghai Province	4500	406.8	97	Several to 100	-1.7 to -3.2
Hengduan Mountains, Southeastern Qinghai-Tibet Plateau	4600-4800	97.2	23	<20	-1.0 to 0
Gangdise and Nyainqentanglha Ranges, Southern TAR	4700-4800	265.6	51	5-100	No Data
Himalaya Range, Southern TAR	4900-5100	152.1	40	<20	-0.5 to 0

Source: Li, Cheng, and Zhou 1996.

limit of permafrost occurs in a pattern similar to that of temperature on the plateau, decreasing steadily towards the northeast of the plateau.

Along the Qinghai-Tibet Highway in the Kunlun Range, just south of Golmud on the northern plateau, the altitudinal limit of permafrost occurs at elevations ranging from 4000-4200 m. However, by the time one reaches the Liangdao He area in the TAR's Amdo County, some 550 km to the southwest of Kunlun Pass, the altitudinal limit of permafrost has shifted upwards by about 450-650 m, occurring between 4640 and 4680 m (Photos 4.2 and 4.3). In general, however, the altitudinal limit of permafrost on the plateau coincides with annual mean surface temperature isotherms ranging between -2.5 and -2.0ºC, while the altitudinal limit of permafrost at a given location would be expected to ascend 150-200 m with a 1ºC increase in

Photo 4.2. Tibetan wild ass herd along the Qinghai-Tibet Highway, southwest Qinghai Province. Photo by Dawa Tsering.

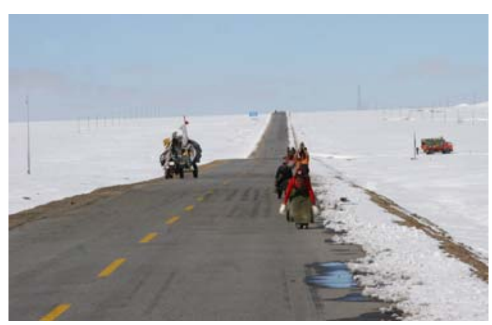

Photo 4.3. Tibetan pilgrims, Qinghai-Tibet Highway, Nagchu Prefecture, TAR. Photo by Dawa Tsering.

annual mean temperature (Cheng, Zhao, and Chen 2000). With an increase in elevation of 100 m in a permafrost zone, the temperature of frozen ground generally decreases by 0.6-1ºC, while the thickness of the permafrost layer increases by about 15-20 m (Liu, Du, and Guo, 2002).

4.3 Changes in Permafrost along the Qinghai-Tibet Highway

4.3.1 Changes in Permafrost during the Quaternary

Over the millennia, permafrost on the Qinghai-Tibet Plateau has undergone a wide range of changes due the plateau's rapid uplift and the changes in climate that accompanied each successive glacial and interglacial period. About 1,100,000 ybp, the Qinghai-Tibet Plateau was uplifted to an elevation of 3500 m above sea level, at which time permafrost was restricted to mountainous areas of the plateau only (Cheng, Zhao, and Chen 2000). The period from 800,000-600,000 ybp was the period of maximum glaciation on the Qinghai-Tibet Plateau. At this time, annual mean temperatures on the plateau ranged from -12 to -4ºC, and permafrost was well developed, particularly in the west of the plateau (Cheng, Zhao, and Chen 2000). This period was followed by a very warm interglacial period, during which permafrost almost entirely disappeared on the Qinghai-Tibet Plateau, only persisting in some areas. At the end of the last glacial period during the late Pleistocene from about 32,000 to 16,000 ybp, the altitudinal limit of permafrost on the Plateau was 1000-1400 m lower than at present (Shi, Zheng, Li, and Ye, 1995; Shi, Li, and Li 1998).

The effects of climatic changes during the Holocene, particularly during the Holocene Neoglaciation (4500-2500 ybp), have also left their mark on the plateau's alpine permafrost areas. During the 1970s, researchers discovered ice layers in geologic core samples collected along the Qinghai-Tibet Highway that occurred at depths of 2-4 m, 7-8 m, and 14-16 m. It can be logically assumed that these ice layers mark the depth of the upper limits of three different episodes of ground freezing, with the two deeper layers being particularly ancient. This assumption is consistent with the conclusions drawn by a number of studies, such as Ding and Guo (1982), who took a mathematical and physical approach to this question; Pu et al. (1982), who examined ice margins; and Wang (1989), who examined stratum structures. All theorize that these three ice layers were formed in the following manner.

During the Holocene Climatic Optimum (about 9000-5000 ybp), the extensive permafrost layer that was formed in the late Pleistocene was melted to a depth of 14-20 m. During the Holocene Neoglaciation, a new layer of frozen ground was formed in a top-down manner to a depth of about 10 m. This new layer of frozen ground did not reach the older, previously formed layer, leaving a layer of unfrozen ground about 5 m thick between the two frozen layers. During a subsequent period

of climatic warming, this second layer was melted to a depth of 7-8 m, after which the third and uppermost layer of frozen ground was formed to a depth of 2-4 m during a more recent period of cooling. However, in many areas of the plateau this uppermost layer disappeared with subsequent climatic warming, leaving only the two deepest, previously formed, frozen ground layers.

4.3.2 Changes in Permafrost from the 1960s to 2002

There is an extensive network of permafrost observation sites along major transportation corridors throughout the permafrost zones of the Qinghai-Tibet Plateau, and these observation sites are regularly monitored to evaluate changes in permafrost conditions (Table 4.2). During the period from 1975-2002, permafrost near the Xidatan Permafrost Observation Site, located just below the northern limit of the plateau's permafrost region, dwindled by 12 percent in area, with the altitudinal limit of permafrost in the area shifting upwards by 25 m (Nan, Gao, Li, and Wu, 2003). From 1975-1996, the 2-km long permafrost island flanking the Qinghai-Tibet Highway near Liangdao He, located at the southern limit of the Qinghai-Tibet Plateau's continuous permafrost zone, decreased in area by 35.6 percent (Wang and Zhao, 1997). At the same time, the altitudinal limit of permafrost in other areas of the plateau also ascended up to 80 m between the 1960s and 1990s (Table 4.3) (Zhao, Chen, Cheng, and Li 2000).

Table 4.2 Permafrost observation sites along the Qinghai-Tibet Highway mentioned in this chapter, listed north to south

Site Code	Site Name	Location	Elevation (m)
Jingxian Gu	North Jingxian Gu	35°46' N, 94°08' E	4480
	Xidatan	35°44' N, 94°15' E	4538
	Kunlun Pass	35°38' N, 94°03' E	4760
	Kunlun-Yakou	35°37' N, 94°05' E	4700
	66 Daoban	35°31' N, 93°48' E	4580
	Xieshui River	35°29' N, 93°40' E	
	Qingshui River	35°26' N, 93°35' E	
K2956	Chumar River	35°18' N, 93°18' E	
	Wudaoliang	35°13' N, 93°05' E	4735
	Hoh Xil	35°08' N, 93°03' E	4740
No.1	Fenghuo Mountain	34°41' N, 92°55' E	4896
CK-7	North Tongtian River		
CK-114	South Tanggula Range	32°48' N, 91°57' E	
	Taoerjiu	32°34' N, 91°52' E	4900
	Amdo South Mountain	32°13' N, 91°42' E	4,800
CK123-7	Liangdao He	31°55' N, 91°42' E	4760
CK123-4	Liangdao He	31°52' N, 91°42' E	

Note: Compiled from various sources. Coordinates and elevations are approximate only.

Table 4.3 Ascent of altitudinal limits of permafrost on the Qinghai-Tibet Plateau, 1960-1990

Permafrost Region	Altitudinal Limit of Permafrost during the 1960s (m)	Altitudinal Limit of Permafrost during the 1990s (m)	Increase in Altitudinal Limit of Permafrost 1960s-1990s (m)
Xidatan	4300	4350	50
Amdo South Mountain	4640	4680	40
Xiangpi Mountain	3700	3780	80
Laji Mountain	3700	3760	60
Heka Mountain South	3840	3900	60
Madoi County	4220	4270	50
Ximen Co Lake North	4070	4140	70
Qilian Range	3420	3500	80

Source: Zhao, Chen, Cheng, and Li 2000.

Table 4.4 Ground Temperatures along the Qinghai-Tibet Highway, 1970s to 2000

Drilling Site Number	CK123-4	CK-7	Jingxian Gu	CK-114	CK 123-7	K2956	No.1
Drilling Site Location	Liangdao He	North Tong Tian River	North Jingxian Gu	South Tanggula Range	Liangdao He	Chumar River	Fenghuo Mountain
Site Type	Seasonally Frozen Ground		Discontinuous Permafrost			Continuous Permafrost	
Ground Temperature in 2000 (ºC)	0.8	0.8	0.3	0.8	-1.0	-0.9	-2.8
Increase in Ground Temperature between the 1970s and 1990s (ºC)	0.3	0.4	0.5	0.3	0.2	0.1	0.2

Source: Zhao, Chen, Cheng, and Li 2000.

During the period from the 1970s-1990s, ground temperatures of continuous permafrost along the northern Qinghai-Tibet Highway increased by 0.1-0.2ºC, while the temperatures of permafrost layers in discontinuous zones increased by 0.2-0.5ºC (Table 4.4) (Zhao, Chen, Cheng, and Li 2000). Of the permafrost observation sites along the Qinghai-Tibet Highway in the Yangtze Source Region discussed here, the maximum increase recorded in permafrost temperature was 0.5ºC at a depth of 5 m below the ground surface at the Hoh Xil site between 1995 and 2000, while the minimum increase of 0.1ºC occurred at the Chumar River Permafrost Observation Site (Fig. 4.2). At the same time, both the Fenghuo Mountain and Kunlun Pass Permafrost Observation Sites experienced a 0.2ºC increase in permafrost temperature (Fig. 4.2). In general, however, the rate of increase in permafrost temperatures decreased with increasing depth during this observation period (Zhang, 2000).

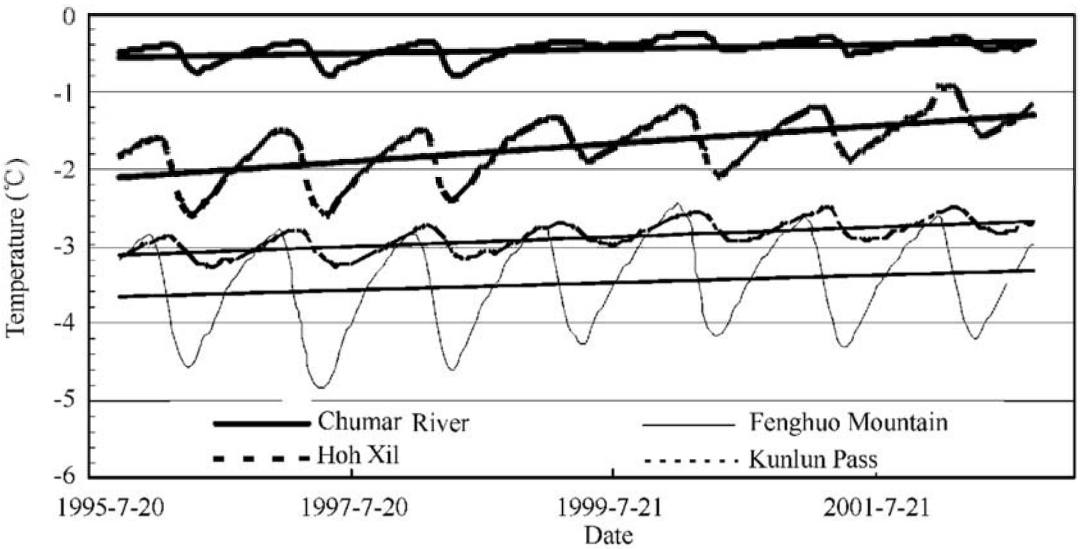

Figure 4.2. Changes in permafrost temperature at a depth of 5 m for four observation sites, 1995-2001.
Source: Cheng and Wu 2007.

Increases in permafrost temperatures have been accompanied by corresponding increases in active layer thicknesses. From the 1980s to the 1990s, the thickness of active layers beneath undisturbed ground along the Qinghai-Tibet Highway typically increased by several centimeters to 1 m, with a maximum increase of 2 m, while from 1995 to 2002, active layers beneath undisturbed ground at four sites along the highway increased by 25-60 cm (Table 4.5, Fig. 4.3) (Wu and Tong 1995, Cheng and Wu 2007). However, areas directly affected by human engineering activities experience much more severe permafrost degradation than undisturbed areas. Asphalt highway pavement affects both ground temperature and ground water, with the quantity of heat penetrating the road base being much larger than the heat being radiated away from the road surface (Sheng, Zhang, Liu, and Wu, 2002; Wang and Wang, 2003). Consequently, from the 1980s to 1990s, active layer thicknesses directly beneath the road surface of the Qinghai-Tibet Highway increased at a much faster rate than beneath adjacent undisturbed ground, typically increasing by 40-150 cm during this period with a maximum increase of 3 m (Table 4.5) (Wu and Tong 1995). Furthermore, from 1995-2002, increases in active layer thicknesses beneath the Qinghai-Tibet Highway road surface were observed to be 20 to 120 cm at four sites (Fig. 4.4). It should be noted, however, that the smallest increases in active layer thicknesses beneath both undisturbed and asphalt surfaces occurred at the lowest temperature sites, specifically the Kunlun Pass and Fenghuo Mountain observation sites (Fig. 4.3).

Table 4.5 Changes in the thicknesses of permafrost active layers along the Qinghai-Tibet Highway, 1980s-1990s

Observation Site	Thickness of Active Layers beneath Undisturbed Ground (m)		Thickness of Active Layers beneath Asphalt Road Surfaces (m)		Site Type
	1980s	1990s	1980s	1990s	
Kunlun Pass	1.0-2.8	1.8-2.8	3.0	4.2	Ice layer with soil
Chumar River	1.0-3.5	2.0-3.5	3.6	4.0	High ice content frozen soil
Wudaoliang	1.0-3.0	2.0-3.5	3.8	4.8	Ice layer with soil
Hoh Xil	1.1-2.5	1.8-3.5	2.9	3.6	Ice layer with soil
Fenghuo Mountain	1.1-2.2	1.3-2.5	2.8	3.4	Ice layer with soil
Tanggula	1.1-3.2	1.5-3.5	2.2	3.0	High ice content frozen soil
Taoerjiu	1.0-2.0	1.3-2.5	2.7	3.8	High ice content frozen soil
Amdo	2.0-3.0	2.2-4.0	2.5	5.5	Frozen soil with ice

Source: Wu and Tong 1995.

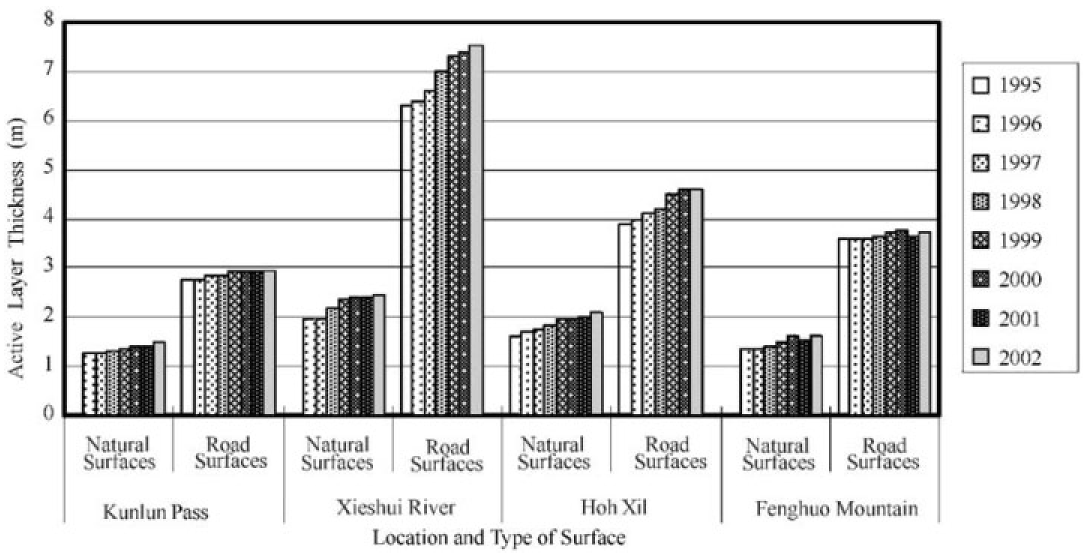

Figure 4.3. Changes in active layer thicknesses beneath both natural and road surfaces along the Qinghai-Tibet Highway, 1995-2002.
Source: Cheng and Wu 2007.

In addition to increases in active layer thicknesses, by 2002 the permafrost melt areas along the Qinghai-Tibet Highway had also expanded significantly in size when compared with the 1960s and 1970s (Wang, Niu, Zhao, and Li, 2003). For example, the total length of the Qinghai-Tibet Highway with permafrost beneath its road base decreased from 550 km in 1979 to 522 km in 1991, a decline of 28 km (Zhao, Cheng, and Ding 2004). By way of comparison, over a similar period the northern limit of undisturbed permafrost on the plateau retreated southwards by only 0.5-1.0 km, while the southern limit retreated northwards by just 1-2 km (Wu and Liu 2004, Wang and Zhao, 1997, both cited in Lemke, Ren, Alley et al. 2007). At the same time, the length of the northern permafrost island, located just north of

the Kunlun Range on the Qinghai Tibet Highway, decreased from 210 km in 1979 to 191 km in 1991, a retreat of 19 km (Zhao, Cheng, and Ding 2004). Meanwhile, the permafrost margins along the Tongtian River have retreated by 1.2 km or more, while the permafrost margins along other rivers have retreated up to 500 m (Wang 2002; cited in Lemke, Ren, Alley et al. 2007).

4.3.3 Recent Changes in Permafrost

From the northern slope of Kunlun Range to the town of Amdo just south of the Tanggula Range, the Qinghai-Tibet Highway crosses a vast region of continuous permafrost where annual mean surface temperatures range from -5.0 to -0.5ºC and the permafrost layer is only interrupted by thawed areas along rivers and other isolated locations. Notes on recent changes in permafrost at various observation sites along the Qinghai-Tibet Highway in this region follow.

4.3.3.1 Xidatan Permafrost Observation Site

The Xidatan Permafrost Observation Site is located beside the Qinghai-Tibet Highway just north of the Kunlun Range in the zone between the northern permafrost island and the plateau's continuous permafrost region, a transitional zone of unstable permafrost that is typical of permafrost areas with annual mean surface temperatures greater than -0.5ºC. As a result of climate warming, changes in permafrost in the Xidatan region in recent years have included increased ground temperatures, increased active layer thicknesses, and reduced permafrost layer depths (Fig. 4.4). The combination of these factors has resulted in the creation of a discontinuous permafrost zone and residual thaw layer and even the complete disappearance of permafrost in some areas as the permafrost zone retreats.

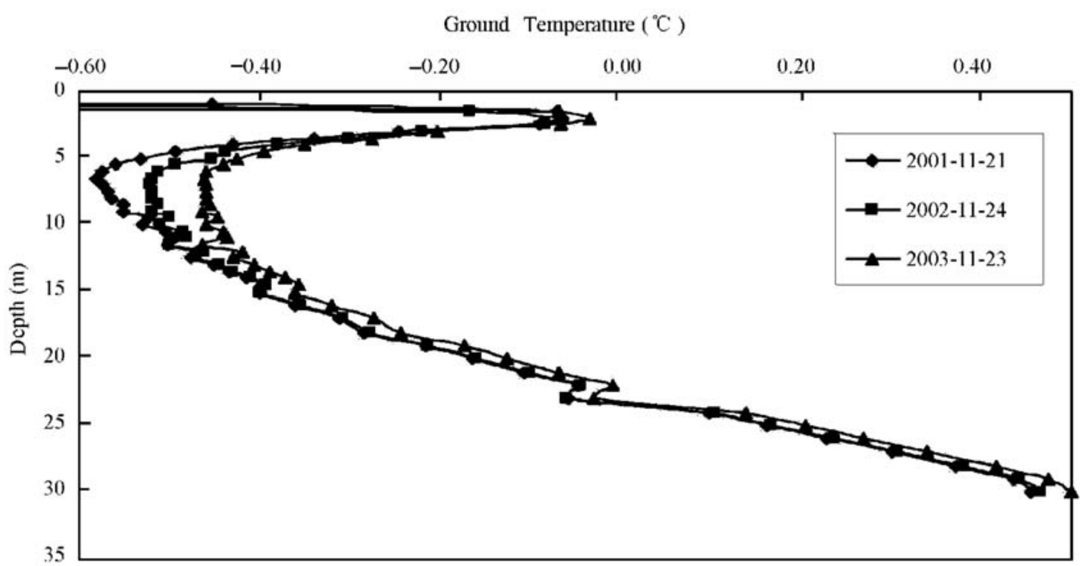

Figure 4.4. Changes in ground temperature at the Xidatan Permafrost Observation Site as measured in November 2001, 2002, 2003.

4.3.3.2 Kunlun-Yakou Permafrost Observation Site

The Kunlun-Yakou Permafrost Observation Site is located at an elevation of 4700 m beside the Qinghai-Tibet Highway on the southern edge of the Kunlun-Yakou Basin, just two kilometers or so south of Kunlun Pass. This observation hole has a depth of 30 m, and temperature readings from November 2001, 2002, and 2003 showed increases in ground temperatures at depths of 3-30 m ranging from 0.07-0.17ºC over this two year period. The average increase in temperature over all depths at this site between November 2001 and November 2003 was 0.11ºC, an average annual rate of warming of 0.055ºC/year (Fig.4.5).

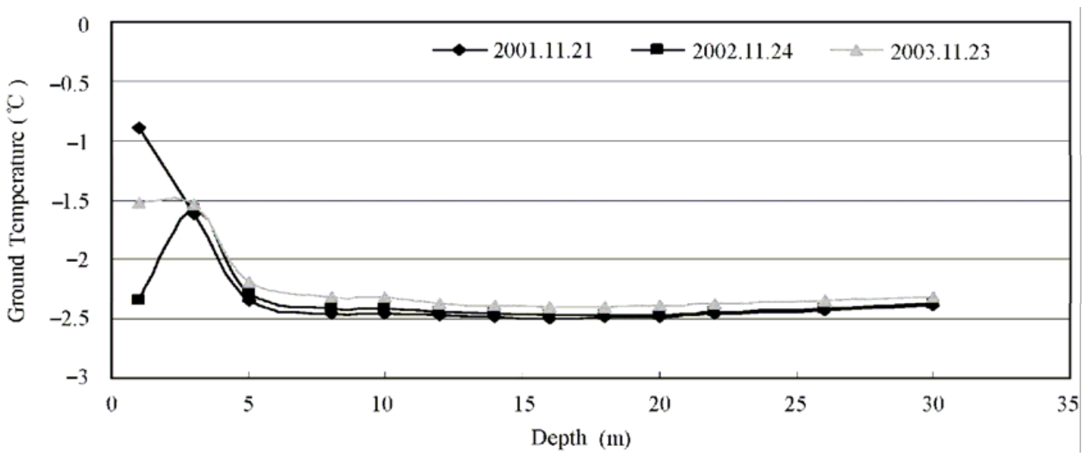

Figure 4.5. Ground temperature at the Kunlun-Yakou Permafrost Observation Site as measured in November 2001, 2002, and 2003.

4.3.3.3 66 Daoban Permafrost Observation Site

The 66 Daoban Permafrost Observation Site is located just south of the Kunlun Range at an elevation of 4580 m beside the Xieshui River in the Chumar River valley fault basin. The observation site is in a flat open area with both standing and running surface water, while the region around the site is dotted with sand dunes and has extremely sparse vegetation cover that leaves 90-95 percent of the ground surface bare. This observation hole has a depth of 17 m and is located in a transitional area between continuous and discontinuous permafrost. The observation site's annual mean ground temperature is about 0.7ºC while active layer thicknesses in the area typically range from 2.0-3.5 m and permafrost depths range from about 15-40 m. Ground temperature data collected from this observation site in November of 2001, 2002, and 2003 shows an average temperature increase of 0.05ºC over all depths for the two year period, or an average annual increase in ground temperature of 0.025ºC/year (Fig.4.6).

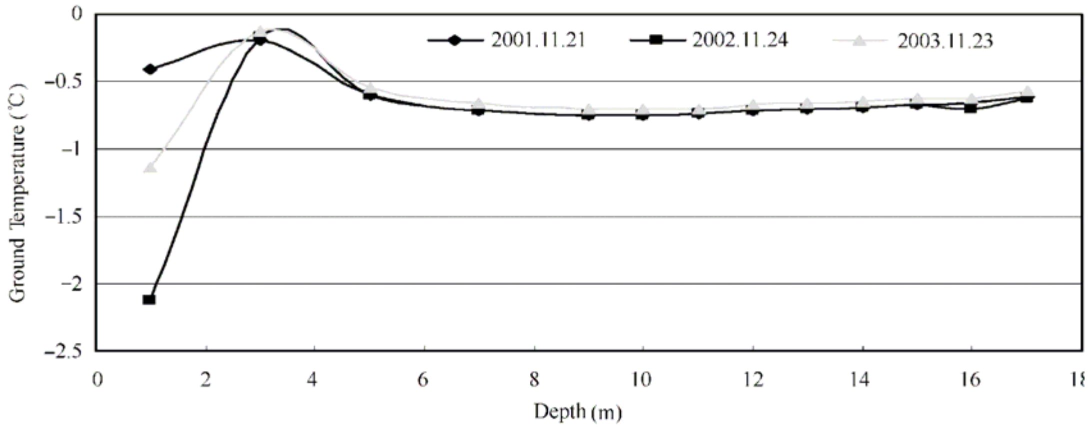

Figure 4.6. Ground temperature at the 66 Daoban Permafrost Observation Site as measured in November 2001, 2002, and 2003.

4.3.3.4 Fenghuo Mountain Permafrost Observation Site

The Fenghuo Mountain Permafrost Observation Site is located at an elevation of 4896 m beside the Qinghai-Tibet Highway in the heart of the plateau's continuous permafrost region, roughly midway between the Kunlun and Tanggula Ranges. The region around the observation site typically ranges in elevation from about 4700-5100 m and permafrost at the site is categorized as "stable," with annual mean ground temperatures ranging from -3.5 to -2.0ºC. Extensive underground ice occurs at the observation site up to a depth of 128.4 m, and the maximum recorded active layer thickness at the site is 2.2 m. Permafrost at the site has an ice content of over 80 percent. The observation hole itself is a 6 m deep hole drilled in undisturbed ground beside the Qinghai-Tibet Highway, and Figure 4.7 shows annual mean ground temperature data collected between 1996 and 2002 at this hole. In general, permafrost at all depths in the observation hole has exhibited a trend towards increasing temperature, although decreases in ground temperature over previous years did occur in 2001 and 2002. Increases in ground temperature were relatively evenly distributed at all depths, although there were much larger increases in temperatures near the soil surface. Data collected from this observation hole shows that between 1996 and 2002, ground temperatures increased by 0.15ºC and 0.44ºC at depths of 1 m and 6 m, respectively. The average increase in ground temperatures over all depths at the Fenghuo Mountain site during this period was 0.32ºC, an annual mean rate of warming of 0.065ºC/year (Wang, Niu, Zhao, and Li 2003).

4.3.3.5 Hoh Xil Permafrost Observation Site

The Hoh Xil Permafrost Observation Site sits at an elevation of 4740 m beside the Qinghai-Tibet Highway about 10 km southwest of the town of Wudaoliang, roughly midway between Fenghuo Mountain and Kunlun Pass. Permafrost at the Hoh Xil observation site is classified as "unstable," while permafrost in the surrounding region is generally considered to be unstable to semi-stable in nature. The depth of the observation hole at the Hoh Xil site is 8 m, and between 1996 and

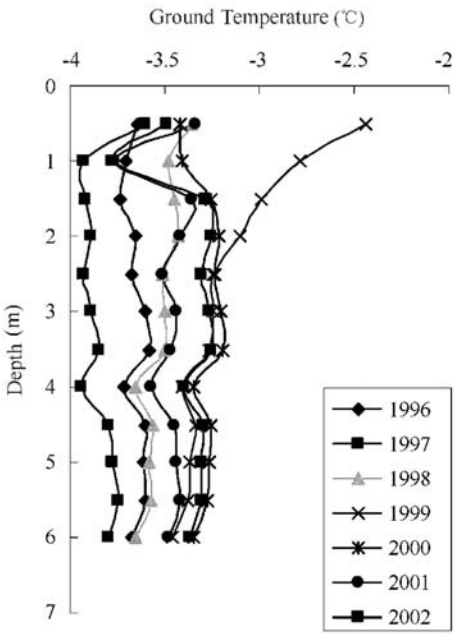

Figure 4.7. Annual mean ground temperatures at the Fenghuo Mountain Permafrost Observation Site, 1996-2002.
Source: Wang, Niu, Zhao, and Li 2003.

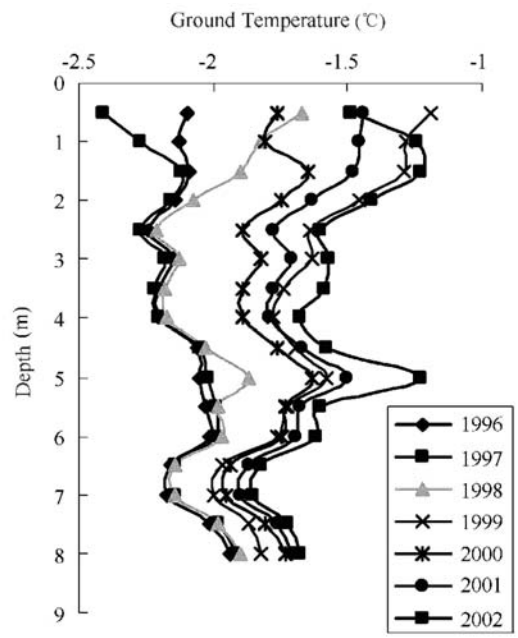

Figure 4.8. Annual mean ground temperatures at the Hoh Xil Permafrost Observation Site, 1996-2002.
Source: Zhao, Wu, Ding, and Xie 2008.

2002 ground temperatures at various depths in the hole increased by a range of 0.07-0.57ºC (Fig.4.8) (Zhao, Wu, Ding, and Xie 2008). During this observation period, the average rate of increase in annual mean ground temperatures over all depths was 0.047ºC/year, which indicates a general warming trend although some year to year variation in this trend did occur (Zhao, Wu, Ding, and Xie 2008).

4.3.3.6 Changes in active layer thickness between Fenghuo Mountain and Xidatan

Figure 4.9 shows the change in active layer thicknesses along the northern Qinghai-Tibet Highway between the Fenghuo Mountain and Xidatan Permafrost Observation Sites from 1996-2004. This figure shows a clear trend of increasing active layer thicknesses along this part of the highway where active layers typically increased by about 50 cm during this period, with average annual increases in active layer thickness ranging from 4.6 to 11 cm/year. In general, increases in active layer thicknesses were more pronounced at observation sites with relatively higher ground temperatures, e.g. at Xidatan, Xieshui River, and Wudaoliang, and less pronounced at observation sites with lower ground temperatures, e.g. at Kunlun Pass and Fenghuo Mountain. The Qingshui River Permafrost Observation Site, which has the thickest active layer of all six sites, experienced a relatively small increase in its active layer thickness of just 40 cm, increasing in total thickness from 3.4 to 3.8 m during this observation period. This low rate of increase is due in large part to the insulating effect of this thick active layer, which has a large capacity to absorb surface heat and shield the permafrost below.

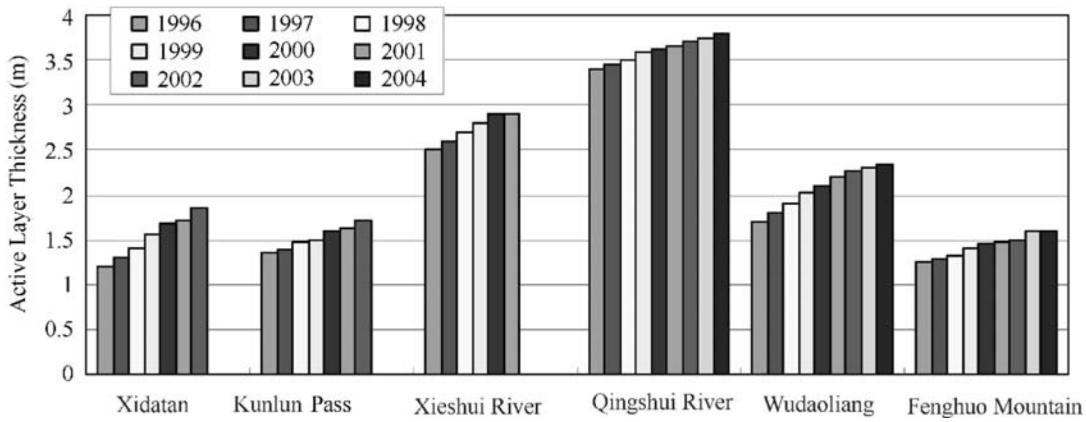

Figure 4.9. Changes in active layer thickness at six permafrost observation sites along the Qinghai-Tibet highway from 1996-2004.

4.4 Conclusions

From the above analysis it is clear that the continuous permafrost zone along the Qinghai-Tibet Highway in the Yangtze Source Region is exhibiting a general trend of increasing ground temperature as a result of regional climate warming. The temperature of stable permafrost at permafrost observation sites in the region has increased at rates ranging from 0.042-0.065ºC/year, while the temperatures of semi-stable and unstable permafrost have increased at rates of 0.016-0.098ºC/year and 0.011-0.041ºC/year, respectively. These increases in ground temperatures are most pronounced during the summer portion of the annual temperature cycle, while in comparison, ground temperature increases during winter are the least pronounced. The magnitude of ground temperature increases on the Qinghai-Tibet Plateau for the period from 1961-2004 have thus far not resulted in significant changes in the plateau's vast continuous permafrost zone with respect to the areal distribution and depth of permafrost. Those changes that have occurred have been primarily limited to the uppermost permafrost, although slight warming of permafrost has also been noted at greater depths.

Nevertheless, it should be noted that the response of ground temperature to climate change is a complicated process, with the time lag and magnitude of this response dependent not only on initial ground temperatures but also on various other factors, such as geological properties and subsurface ice content of an area. Yet, it can be safely assumed that sustained increases in atmospheric temperatures across the Qinghai-Tibet Plateau will impact ground temperatures of deep permafrost in coming decades. Previous studies have shown that the impact of climate change is larger on high-temperature permafrost with annual mean ground temperatures above -1.5ºC than on low-temperature permafrost with annual mean

ground temperatures below -1.5ºC, which is generally more stable and less sensitive to atmospheric temperature changes. However, the above-mentioned studies also found that climate change induced ground temperature increases in low temperature permafrost were significantly larger than those that occurred in high temperature permafrost. Thus, climatic warming is expected to have a large impact on the stability of permafrost on the Qinghai-Tibet Plateau in coming decades, which in turn will have tremendous consequences for the ecosystems, surface water resources, and economic development of the entire region.

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5

Views of Livestock Herders and Others Concerning the Impact of Climate Change on the Yangtze Source Region

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5.1 Introduction

The Yangtze Source Region is located in southwest Qinghai Province where average elevations exceed 4000 m and the climate is extremely cold and harsh. (Photo 5.1). There are two primary seasons in the region, a long cold season lasting from early November to mid-May, and a shorter warm season lasting the remainder of the year. The region is arid, only receiving about 200-600 mm of precipitation annually, and what little precipitation that falls is generally concentrated during the short rainy season in July and August. Ecosystems in the Yangtze Source Region are predominately high altitude, permafrost-controlled grasslands. Due to the re-

Photo 5.1. Yangtze Source Region, southwest Qinghai Province. File photo.

Photo 5.2. Yak herder's pasture, Yangtze Source Region, Jyekundo County, Qinghai Province. Photo by Yifei Zhang.

gion's harsh climate and extensive grasslands, livestock herding is the primary economic activity for the majority of the region's residents (Photo 5.2). As discussed in the preceding chapters of this report, the direct impacts of climate change on the Yangtze Source Region are growing rapidly in magnitude and include changing patterns of temperature, precipitation, and evaporation; the loss of snow and glacier cover; melting of permafrost; changes in the size of lakes and wetlands; decreased grassland productivity; and in extreme cases, desertification. Thus, climate change is an important factor that needs to be considered when developing a strategy for the sustainable development of the Yangtze Source Region. In order to learn more about the views of residents of the Yangtze Source Region concerning the impact of climate change on the local environment, in the summer of 2005 the Chinese Academy of Social Sciences (CASS) conducted a social survey of the region's inhabitants, the results of which follow.

5.2 Climate Change Survey Methodology

The CASS social survey on climate change was conducted in Qinghai's Zhidoi County from June 12 to July 1, 2005, and in neighboring Chumarleb County from July 2-16, 2005, both counties being located in the heart of the Yangtze Source Region (Photo 5.3). The survey questionnaire consisted of four sections on: 1) local residents' perceptions of climate change, 2) the impact of climate change on local ecosystems and livestock herding, 3) the impact of climate change on local problems of pasture degradation and desertification, and 4) the impact of climate change on the decline in area of pasturelands suitable for grazing domestic livestock in the region. All survey questions were accompanied by a multiple choice list of predetermined answers, with each question having a range of four to seventeen choices of possible responses. For most questions, survey respondents were only allowed to choose one answer, however, for a number of questions, survey respondents were allowed to choose up to three possible responses.

Photo 5.3. Nieqia River, Zhidoi County, Qinghai. Photo by Gang Xie.

Two-hundred residents of Chumarleb, Zhidoi, and Jyekundo Counties were interviewed for the survey (Tables 5.1 and 5.2). Since only one resident of Jyekundo County was interviewed for this survey, all of this respondent's survey answers have been included in the data analysis for Zhidoi County. The majority of survey respondents were male Tibetan livestock herders, and the ages of survey respondents ranged from teenagers to elderly residents of the survey area. Notably,

Photo 5.4. Tibetan herding family, Chang Tang steppe grasslands, Nagchu Prefecture, TAR. Photo by Dawa Tsering.

Photo 5.5. Tibetan herder, Chang Tang steppe grasslands, Nagchu Prefecture, TAR. Photo by Dawa Tsering.

Photo 5.6. Tibetan herder and child, Nagchu Prefecture, TAR. Photo by Dawa Tsering.

Photo 5.7. Tibetan herder children, Nagchu Prefecture, TAR. Photo by Dawa Tsering.

Table 5.1 Number of survey respondents by county

County	Number of Survey Respondents	Percentage of Survey Respondents
Chumarleb	106	53.0
Zhidoi	93	46.5
Jyekundo	1	0.5
Total	200	100 %

54 respondents were 30 years of age or younger in the summer of 2005, many of whom obviously do not have memories of what the local climate was like prior to the onset of rapid increases in temperatures in the Yangtze Source Region in the late 1970s and early 1980s (Tables 5.3, 5.4, 5.5, and 5.6; Photos 5.4, 5.5, 5.6, and 5.7). Responses to all survey questions were compiled and analyzed on the basis of: 1) the survey total, 2) county, 3) the respondent's occupation, which for the sake of analysis was simplified throughout this report to two broad categories, herders and non-herders, and 4) the type of ecosystem respondents inhabited, which were simply categorized as alpine wet meadows, alpine meadows, alpine steppe, and town centers, including county seats, township centers, and village centers. (Table 5.7 and 5.8; Photo 5.8).

The survey team consisted of five primary researchers, two from the Chinese Academy of Social Sciences, Beijing; two researchers from the Sanjiangyuan Ecosystem Protection Association, Jyekundo, who were both local Tibetans; and one researcher from the Chinese Academy of Sciences Institute of Botany, Kunming. This team was assisted by one assistant researcher from the Chinese Academy of Social Sciences, Beijing; three staff members of the Sanjiangyuan Ecosystem Protection Association, Jyekundo; as well as six local primary school teachers from both Zhidoi and Chumarleb Counties.

Photo 5.8. Wet meadows, Longbaotan National Nature Reserve, Yangtze Source Region, Jyekundo County, Qinghai. Photo by Yifei Zhang.

Table 5.2 List of locations where the survey was conducted

Survey Site Name	Number of Survey Respondents	Percentage of Survey Respondents (%)
Jyekundo County Subtotal	**1**	**0.5**
Jyekundo (Jyekundo County Seat)	1	0.5
Zhidoi County Subtotal	**93**	**46.5**
Gyelje Podrang (Zhidoi County Seat)	15	7.5
Dangjiang Township Center	2	1.0
Zhiqu Township Center	1	0.5
Duocai Township		
- Lari Village	1	0.5
Zhahe Township Center	3	1.5
- Masai Village	1	0.5
- Zhisai Village	2	1.0
- Kouqian Village	11	5.5
Suojia Township		
- Yaqu Village	4	2.0
- Moqu Village	53	26.5
Chumarleb County Subtotal	**106**	**53**
Chumarleb (Chumarleb County Seat)	14	7.0
Maduo Township		
- Gouyang Village	1	0.5
Yege Township		
- Longma Village	1	0.5
- Laiyong Village	1	0.5
- Leyang Village	6	3.0
Chumar River Township Center	17	8.5
- Acai Village	1	0.5
- Duoxiu Village	3	1.5
- Angla Village	5	2.5
- LechiVillage	7	3.5
- Cuochi Village	50	25.0
Total	**200**	**100**

Table 5.3 Number of survey respondents by gender

Sex	Number of Survey Respondents	Percentage of Survey Respondents
Male	166	83.0
Female	34	17.0
Total	200	100 %

Table 5.4 Number of survey respondents by ethnicity

Ethnicity	Number of Survey Respondents	Percentage of Survey Respondents
Tibetan	192	96.0
Han	7	3.5
Hui	1	0.5
Total	200	100 %

Table 5.5 Number of survey respondents by occupation

Occupation	Number of Survey Respondents	Percentage of Survey Respondents
Herder	133	66.5
Teacher	20	10.0
Farm Hand	17	8.5
Livestock Bureau Staff Members	14	7.0
Town Dwellers	5	2.5
Peasant	4	2.0
Religious Figure	3	1.5
Government Bureaucrats	2	1.0
Other	2	1.0
Total Herders	133	66.5
Total Non-herders	67	33.5
Total	200	100 %

Table 5.6 Number of survey respondents by age

Age (years)	Number of Survey Respondents	Percentage of Survey Respondents
≤ 18	2	1.0
19-25	16	8.0
26-30	36	18.0
31-40	71	35.5
41-50	31	15.5
51-55	10	5.0
56-60	19	9.0
> 61	15	7.0
Total	200	100 %

Table 5.7 Number of survey respondents by type of grassland occupied

Location Type	Number of Survey Respondents	Percentage of Survey Respondents
Alpine Wet Meadows	53	26.5
Alpine Meadows	52	26.0
Alpine Steppe	66	33.0
Town Centers	29	14.5
Total	200	100 %

Note: There is a slight discrepancy in the number of town dwellers and the number of people interviewed in towns (Table 5.2, above) as some rural residents were interviewed in administrative centers.

Table 5.8 Number of survey respondents by type of grassland occupied and survey site location

Survey Site Name	**Number of Survey Respondents Inhabiting Alpine Wet Meadows**	**Number of Survey Respondents Inhabiting Alpine Meadows**	**Number of Survey Respondents Inhabiting Alpine Steppe**	**Number of Survey Respondents Inhabiting Town Centers**
Jyekundo County Subtotal	**0**	**0**	**0**	**1**
Jyekundo (Jyekundo County Seat)	—	—	—	1
Zhidoi County Subtotal	**28**	**16**	**34**	**15**
Gyelje Podrang (Zhidoi County Seat)	—	—	1	14
Dangjiang Township Center	—	2	—	—
Zhiqu Township Center	1	—	—	—
Duocai Township				
- Lari Village	1	—	—	—
Zhahe Township Center	—	2	—	1
- Masai Village	—	—	1	—
- Zhisai Village	2	—	—	—
- Kouqian Village	6	1	4	—
Suojia Township				
- Yaqu Village	3	1	—	—
- Moqu Village	15	10	28	—
Chumarleb County Subtotal	**25**	**36**	**32**	**13**
Chumarleb (Chumarleb County Seat)	—	—	2	12
Maduo Township				
- Gouyang Village	—	1	—	—
Yege Township				
- Longma Village	—	1	—	—
- Laiyong Village	—	—	1	—
- Leyang Village	—	1	5	—
Chumar River Township Center	—	6	10	1
- Acai Village	—	1	—	—
- Duoxiu Village	1	—	2	—
- Angla Village	1	3	1	—
- Lechi Village	—	3	4	—
- Cuochi Village	23	20	7	—
Survey Total	**53**	**52**	**66**	**29**

5.3 Local Residents' Perceptions of Climate Change

In the first survey section, survey respondents were asked about the degree and timing of climate change in their communities, their general perceptions of local climatic changes, and about more specific changes in temperature and weather phenomena during both the warm and cold seasons.

5.3.1 Survey Question 1: In your opinion, has the appearance of climate change in this locality been obvious or not?

Table 5.9 Degree of obviousness of changes in the local climate, all survey respondents

Degree of Obviousness of Climate Change	Number of Survey Respondents	Percentage of Survey Respondents
Very Obvious	101	50.5
Fairly Obvious	68	34.0
Somewhat Obvious	27	13.5
Not Obvious	3	1.5
Hasn't Occurred	1	0.5
Total	200	100 %

Table 5.10 Degree of obviousness of changes in the local climate by county

County	Zhidoi County		Chumarleb County	
Degree of Obviousness of Climate Change	Number of Surveyed Zhidoi County Residents	Percentage of Surveyed Zhidoi County Residents	Number of Surveyed Chumarleb County Residents	Percentage of Surveyed Chumarleb County Residents
Very Obvious	32	34.0	69	65.1
Fairly Obvious	38	40.4	30	28.3
Somewhat Obvious	20	21.7	7	6.6
Not Obvious	3	3.2	0	0
Hasn't Occurred	1	1.1	0	0
Total	94	100 %	106	100 %

Table 5.11 Degree of obviousness of changes in the local climate by occupation

Occupation	**Herders**		**Non-Herders**	
Degree of Obviousness of Climate Change	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Very Obvious	75	56.4	26	38.8
Fairly Obvious	45	33.8	23	34.3
Somewhat Obvious	10	7.5	17	25.4
Not Obvious	2	1.5	1	1.5
Hasn’t Occurred	1	0.8	0	0
Total	133	100 %	67	100 %

Table 5.12 Degree of obviousness of changes in the local climate by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Degree of Obviousness of Climate Change	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Very Obvious	32	60.4	27	51.9	31	47.0
Fairly Obvious	15	28.3	18	34.6	26	39.4
Somewhat Obvious	6	11.3	7	13.5	6	9.1
Not Obvious	0	0	0	0	2	3.0
Hasn’t Occurred	0	0	0	0	1	1.5
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of the 200 survey respondents, the vast majority, 84.5 percent, felt that there had been either “fairly obvious” or “very obvious” changes in the climate of the Yangtze Source Region (Table 5.9). However, individuals expressed a varying degree of sensitivity to climate issues depending on their home county and occupation, and to a lesser extent on the type of grassland they inhabited. In Chumarleb County, 65.1 percent of respondents felt that there had been “very obvious” changes in the local climate versus just 34 percent of respondents from Zhidoi County (Table 5.10). Notably, 56.4 percent of herders felt that there had been “very obvious” changes in the local climate versus just 38.8 percent of non-herders participating in the survey (Table 5.11). When analyzed by type of grassland inhabited, 60.4 percent, 51.9 percent, and 47 percent of survey respondents residing on alpine wet meadows, alpine meadows, and alpine steppe, respectively, stated there had been “very obvious” changes in the local climate (Table 5.12).

5.3.2 Survey Question 2: In your opinion, when did the most obvious changes in the local climate occur?

Table 5.13 Period of occurrence of the most obvious changes in the local climate, all survey respondents

Onset of Most Obvious Changes in Climate	Number of Survey Respondents	Percentage of Survey Respondents
Before 1950	0	0
1950-1969	0	0
1970-1979	2	1.0
1980-1989	53	26.5
1990-1999	55	27.5
2000-2005	81	40.5
Hasn't Occurred	5	2.5
Don't Remember	4	2.0
Total	200	100 %

Table 5.14 Period of occurrence of the most obvious changes in the local climate by county

County	Zhidoi County		Chumarleb County	
Onset of Most Obvious Changes in Climate	Number of Surveyed Zhidoi County Residents	Percentage of Surveyed Zhidoi County Residents	Number of Surveyed Chumarleb County Residents	Percentage of Surveyed Chumarleb County Residents
Before 1950	0	0	0	0
1950-1969	0	0	0	0
1970-1979	1	1.1	1	0.9
1980-1989	27	28.7	26	24.5
1990-1999	21	22.3	34	32.1
2000-2005	40	42.6	41	38.7
Hasn't Occurred	3	3.2	2	1.9
Don't Remember	2	2.1	2	1.9
Total	94	100 %	106	100 %

Table 5.15 Period of occurrence of the most obvious changes in the local climate by occupation

Occupation	**Herders**		**Non-herders**	
Onset of Most Obvious Changes in Climate	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Before 1950	0	0	0	0
1950-1969	0	0	0	0
1970-1979	0	0	2	3.0
1980-1989	42	31.6	11	16.4
1990-1999	33	24.8	22	32.8
2000-2005	52	39.1	29	43.3
Hasn't Occurred	2	1.5	3	4.5
Don't Remember	4	3.0	0	0
Total	133	100 %	67	100 %

Table 5.16 Period of occurrence of the most obvious changes in the local climate by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Onset of Most Obvious Changes in Climate	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Before 1950	0	0	0	0	0	0
1950-1969	0	0	0	0	0	0
1970-1979	0	0	1	1.9	0	0
1980-1989	12	22.6	11	21.2	24	36.4
1990-1999	13	24.5	14	26.9	16	24.2
2000-2005	26	49.1	26	50.0	21	31.8
Hasn't Occurred	0	0	0	0	3	4.6
Don't Remember	2	3.8	0	0	2	3.0
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Table 5.17 Period of occurrence of the most obvious changes in the local climate by age

Respondent's Age/ Time Period	≤18	19-25	26-30	31-40	41-50	51-55	56-60	≥ 61
Before 1950	—	—	—	—	—	—	—	—
1950-1969	—	—	—	—	—	—	—	—
1970-1979	—	—	1	—	—	—	1	—
1980-1989	—	—	9	15	11	3	8	7
1990-1999	—	4	5	27	9	3	5	2
2000-2005	2	9	19	26	11	4	5	5
Hasn't Occurred	—	2	1	1	—	—	—	1
Don't Remember	—	1	1	2	—	—	—	—
Total	2	16	36	71	31	10	19	15

Of the 200 survey respondents, 94.5 percent stated that the most obvious changes in the local climate occurred between 1980 and 2005, with largest share, 40.5 percent of all respondents, stating that the most obvious changes in the local climate had occurred since 2000 (Table 5.13). Forty survey respondents (20 percent) stated that the most obvious changes in climate had occurred during 2005, the year in which the survey was conducted. With respect to home county, a similar 42.6 percent and 38.7 percent of survey respondents from Zhidoi and Chumarleb Counties, respectively, felt that the most obvious changes in the local climate had occurred since 2000, which included 39.1 percent of herders surveyed and 43.3 percent of non-herders (Table 5.14 and 5.15). In terms of the type of grassland inhabited, a similar 49.1 percent and 50 percent of survey respondents dwelling on wet meadows and alpine meadows, respectively, felt that the most obvious changes in the local climate had occurred since 2000, versus just 31.8 percent of alpine steppe dwellers, the largest share of whom (36.4 percent) felt that the most obvious changes in the local climate had occurred during the 1980s (Table 5.16). It should be noted, however, that there was some skewing of responses to this question based on age, with younger respondents clearly feeling that the onset of obvious changes in the local climate began later than did older respondents (Table 5.17).

5.3.3 Survey Question 3: If the climate has changed, in your opinion, is summer cooler or hotter now?

Table 5.18 Perceptions of change in summer temperatures, all survey respondents

Perceptions of Change in Summer Temperatures	Number of Survey Respondents	Percentage of Survey Respondents
Cooler	134	67.0
Hotter	52	26.0
No Obvious Change	14	7.0
Total	200	100 %

Table 5.19 Perceptions of change in summer temperatures, by county

County	Zhidoi County		Chumarleb County	
Perceptions of Change in Summer Temperatures	**Number of Surveyed Zhidoi County Residents**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Surveyed Chumarleb County Residents**	**Percentage of Surveyed Chumarleb County Residents**
Cooler	64	68.1	71	67.0
Hotter	24	25.5	28	26.4
No Obvious Change	6	6.4	7	6.6
Total	94	100 %	106	100 %

Table 5.20 Perceptions of change in summer temperatures, by occupation

Occupation	Herders		Non-Herders	
Perceptions of Change in Summer Temperatures	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Cooler	112	84.2	23	34.3
Hotter	13	9.8	39	58.2
No Obvious Change	8	6.0	5	7.5
Total	133	100 %	67	100 %

Table 5.21 Perceptions of change in summer temperatures, by type of grassland inhabited

Grassland Type	Alpine Wet Meadow		Alpine Meadow		Alpine Steppe	
Perceptions of Change in Summer Tempera-tures	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Cooler	45	84.9	35	67.3	47	71.2
Hotter	4	7.6	13	25.0	16	24.2
No Obvious Change	4	7.6	4	7.7	3	4.6
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of the 200 survey respondents, a large majority, 67 percent, felt that warm season in the survey area is now cooler than in former times (Table 5.18). These respondents included a similar 68.1 percent and 67 percent of those surveyed in Zhidoi and Chumarleb Counties, respectively (Table 5.19). Notably, however, 84.2 percent of herders surveyed felt that the local summer is now cooler, while in stark contrast, 58.2 percent of non-herders felt that summer is now hotter (Table 5.20). In terms of the type of grassland inhabited, an overwhelming 84.9 percent of alpine wet meadow residents felt that the local climate is now cooler, as compared to 67.3

percent of alpine meadow residents and 71.2 percent of alpine steppe residents who felt that summer is now cooler (Table 5.21).

5.3.4 Survey Question 4: In your opinion, what are the principal manifestations of climate change in summer?

Table 5.22 Principal manifestations of climate change in summer, all survey respondents

Principal Changes in Climate Phenomena in Summer	Number of Responses	Percentage of All Responses	Percentage of Survey Respondents
More Snowfall	102	19.7	51.0
More High Wind Events	93	18.0	46.5
Summer Shorter	92	17.8	46.0
Summer Cooler	73	14.1	36.5
Less Rainfall	59	11.4	29.5
More Glacier and Snow Meltoff	43	8.3	21.5
Summer Warmer	24	4.6	12.0
Summer Longer	10	1.9	5.0
Fewer High Wind Events	5	1.0	2.5
Other	16	3.1	8.0
Total	517	100	N/A

Note: Survey respondents were permitted to cite up to three phenomena. Percentages are based on 200 survey respondents.

Table 5.23 Principal manifestations of climate change in summer, by county
CountyZhidoi CountyChumarleb County

County	**Zhidoi County**		**Chumarleb County**	
Principal Changes in Climate Phenomena in Summer	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
More Snowfall	55	58.5	47	44.3
More High Wind Events	35	37.2	59	55.7
Summer Shorter	40	42.6	51	48.1
Summer Cooler	36	38.3	37	34.9
Less Rainfall	28	29.8	31	29.2
More Glacier and Snow Meltoff	28	29.8	15	14.2
Summer Warmer	14	14.9	10	9.4
Summer Longer	8	8.5	2	1.9
Fewer High Wind Events	3	3.2	2	1.9
Other	7	7.4	9	8.5
Total	254	N/A	263	N/A

Note: Survey respondents were permitted to cite up to three phenomena. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.24 Principal manifestations of climate change in summer, by occupation

Occupation	**Herders**		**Non-Herders**	
Principal Changes in Climate Phenomena in Summer	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
More Snowfall	63	47.4	39	58.2
More High Wind Events	74	55.6	20	29.9
Summer Shorter	69	51.9	22	32.8
Summer Cooler	66	49.6	7	10.4
Less Rainfall	50	37.6	9	13.4
More Glacier and Snow Meltoff	16	12.0	27	40.3
Summer Warmer	9	6.8	15	22.4
Summer Longer	8	6.0	2	3.0
Fewer High Wind Events	4	3.0	1	1.5
Other	12	9.0	4	6.0
Total	371	N/A	146	N/A

Note: Survey respondents were permitted to cite up to three phenomena. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.25 Principal manifestations of climate change in summer, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Principal Changes in Climate Phenomena in Summer	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
More Snowfall	24	45.3	28	53.8	30	49.2
More High Wind Events	25	47.2	26	50.0	37	60.7
Summer Shorter	34	64.2	23	44.2	32	52.5
Summer Cooler	23	43.4	19	36.5	29	47.5
Less Rainfall	19	35.8	16	30.8	24	39.3
More Glacier and Snow Meltoff	8	15.1	10	19.2	9	14.8
Summer Warmer	3	5.7	6	11.5	5	8.2
Summer Longer	2	3.8	1	1.9	6	9.8
Fewer High Wind Events	1	1.9	1	1.9	3	4.9
Other	5	9.4	3	5.8	6	9.8
Total	144	N/A	133	N/A	181	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three phenomena. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

Survey respondents cited a wide array of changes in summer weather phenomena that they felt were indicative of a changing climate during the local warm season, the most commonly stated of which were an increase in the occurrence of snowfall in summer (cited by 51 percent of survey respondents), an increase in summer high wind events (46.5 percent of survey respondents), a decrease in the duration of summer (46 percent of survey respondents), a general cooling of local temperatures in summer (36.5 percent of survey respondents), and a decrease in summer rainfall (29.5 percent of survey respondents) (Table 5.22). Similarly, the two most common changes in summer weather phenomena cited by residents of Zhidoi and Chumarleb Counties were increased summer snowfall (58.5 and 44.3 percent of survey respondents, respectively) and an increase in high wind events (37.2 and 55.7 percent of survey respondents, respectively) (Table 5.23). In

terms of occupation, herders and non-herders had similar perceptions of increased summer snowfall (47.4 and 58.2 percent, respectively). However, their perceptions of increased summer high wind events were markedly different, being by cited 55.6 percent and 29.9 percent of surveyed herders and non-herders, respectively (Table 5.24). Other notable differences in summer phenomena cited by herders and non-herders were the perception of summer being shorter now than formerly, cited by 51.9 percent of herders versus 32.8 percent of non-herders, and the phenomena of summer now being cooler, cited by 49.6 percent of herders versus just 10.4 percent of non-herders (Table 5.24). In terms of type of grassland inhabited, the most frequently cited summer climate change phenomena cited by inhabitants of alpine wet meadows was summer being shorter now (64.2 percent of wet meadow respondents), while residents of alpine meadows most frequently cited more summer snowfall (53.8 of alpine meadow respondents) and inhabitants of alpine steppe areas most frequently cited more high wind events (60.7 percent of alpine steppe respondents) (Table 5.25).

5.3.5 Survey Question 5: If the climate has changed, in your opinion, is winter colder or warmer now?

Table 5.26 Perceptions of change in winter temperatures, all survey respondents

Perceptions of Change in Winter Temperatures	Number of Survey Respondents	Percentage of Survey Respondents
Colder	73	36.5
Warmer	100	50.0
No Obvious Change	27	13.5
Total	200	100 %

Table 5.27 Perceptions of change in winter temperatures, by county

County	Zhidoi County		Chumarleb County	
Perceptions of Change in Winter Temperatures	Number of Surveyed Zhidoi County Residents	Percentage of Surveyed Zhidoi County Residents	Number of Surveyed Chumarleb County Residents	Percentage of Surveyed Chumarleb County Residents
Colder	21	22.3	53	50.0
Warmer	59	62.8	40	37.7
No Obvious Change	14	14.9	13	12.3
Total	94	100 %	106	100 %

Table 5.28 Perceptions of change in winter temperatures, by occupation

Occupation	**Herders**		**Non-Herders**	
Perceptions of Change in Winter Temperatures	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Colder	56	42.1	18	26.9
Warmer	56	42.1	43	64.2
No Obvious Change	21	15.8	6	9.0
Total	133	100 %	67	100 %

Table 5.29 Perceptions of change in winter temperatures, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Perceptions of Change in Winter Temperatures	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Colder	19	35.9	20	38.5	27	40.9
Warmer	27	50.9	25	48.1	28	42.4
No Obvious Change	7	13.2	7	13.5	11	16.7
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of the 200 survey respondents in the Yangtze Source Region, 50 percent felt that temperatures during winter are now warmer than in previous years versus 36.5 percent of survey respondents who felt winters had grown colder (Table 5.26). However, there was a distinct difference between the views of residents of the two surveyed counties, with 62.8 percent of residents of Zhidoi County of the opinion that winters are now warmer versus just 37.7 percent of residents of Chumarleb County, 50 percent of whom actually felt that winters are now colder (Table 5.27). In terms of occupation, there was an even split among herders, with 42.1 percent of herders surveyed stating that winters were both colder and warmer, while a majority (64.2 percent) of non-herders surveyed were of the opinion that winters are now warmer (Table 5.28). The most common response amongst grassland dwellers surveyed was that winters are now warmer, as stated by 50.9, 48.1, and 42.4 percent of alpine wet meadow, alpine meadow, and alpine steppe residents surveyed, respectively (Table 5.29).

5.3.6 Survey Question 6: In your opinion, what are the principal manifestations of climate change in winter?

Table 5.30 Principal manifestations of climate change in winter, all survey respondents

Principal Changes in Climate Phenomena in Winter	Number of Responses	Percentage of All Responses	Percentage of Survey Respondents
More High Wind Events	118	24.6	59.0
Less Snowfall	88	18.3	44.0
Winter Longer	79	16.5	39.5
Winter Warmer	71	14.8	35.5
More Snowfall	46	9.6	23.0
Winter Colder	43	9.0	21.5
Fewer High Wind Events	22	4.6	11.0
Winter Shorter	9	1.9	4.5
Other	4	0.8	2.0
Total	480	100 %	N/A

Note: Survey respondents were permitted to cite up to three phenomena. Percentages are based on 200 survey respondents.

Table 5.31 Principal manifestations of climate change in winter, by county

County	Zhidoi County		Chumarleb County	
Principal Changes in Climate Phenomena in Winter	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
More High Wind Events	40	42.6	79	74.5
Less Snowfall	64	68.1	24	22.6
Winter Longer	38	40.4	41	38.7
Winter Warmer	45	47.9	26	24.5
More Snowfall	10	10.6	34	32.1
Winter Colder	15	16.0	28	26.4
Fewer High Wind Events	19	20.2	3	2.8
Winter Shorter	6	6.4	3	2.8
Other	2	2.1	2	1.9
Total	239	N/A	240	N/A

Note: Survey respondents were permitted to cite up to three phenomena. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.32 Principal manifestations of climate change in winter, by occupation

Occupation	**Herders**		**Non-Herders**	
Principal Changes in Climate Phenomena in Winter	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
More High Wind Events	85	63.9	34	50.7
Less Snowfall	63	47.4	25	37.3
Winter Longer	59	44.4	20	29.9
Winter Warmer	39	29.3	32	47.8
More Snowfall	34	25.6	10	14.9
Winter Colder	37	27.8	6	9.0
Fewer High Wind Events	11	8.3	11	16.4
Winter Shorter	8	6.0	1	1.5
Other	3	2.3	1	1.5
Total	339	N/A	140	N/A

Note: Survey respondents were permitted to cite up to three phenomena. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.33 Principal manifestations of climate change in winter, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Principal Changes in Climate Phenomena in Winter	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
More High Wind Events	29	54.7	35	67.3	37	56.1
Less Snowfall	33	62.3	16	30.8	29	43.9
Winter Longer	20	37.7	19	36.5	35	53.0
Winter Warmer	16	30.2	18	34.6	20	30.3
More Snowfall	9	17.0	17	32.7	15	22.7
Winter Colder	13	24.5	14	26.9	14	21.2
Fewer High Wind Events	7	13.2	3	5.8	5	7.6
Winter Shorter	6	11.3	3	5.8	0	0
Other	2	3.8	0	0	2	3.0
Total	135	N/A	125	N/A	157	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three phenomena. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

When residents of the survey area were asked what they considered to be the primary changes in winter weather phenomena in the Yangtze Source Region, the most commonly cited changes were more high wind events (59 percent of survey respondents), less snowfall (44 percent of survey respondents), a lengthening of winter (39.5 percent of survey respondents), and warmer winter temperatures (35.5 percent of survey respondents) (Table 5.30). While similar percentages of residents of both Zhidoi and Chumarleb Counties felt that winters are now of longer duration (40.4 and 38.7 percent of survey respondents, respectively), in other respects there were wide differences in opinion between respondents of the two counties (Table 5.31). With respect to high wind events, 42.6 percent of survey respondents from Zhidoi cited an increase in the frequency of high wind events versus an overwhelming 74.5 percent of respondents from Chumarleb County (Table 5.31). There was an even larger split by county on the question of decreasing winter snowfall, with 68.1 percent of respondents from Zhidoi County feeling snowfall had decreased versus just 22.6 percent of respondents from Chumarleb County (Table 5.31). At 47.9 percent, nearly twice as many respondents from Zhidoi County cited warmer winters than in Chumarleb County (24.5 percent of survey respondents) (Table 5.31). In terms of occupation, 63.9 percent and 50.7 percent of surveyed herders and non-herders, respectively, cited an increase in high wind events, while notably, 29.3 percent of herders cited warmer winters versus 47.8 percent of non-herders (Table 5.32). In terms of the type of grassland occupied, the largest variation in responses of the four most commonly cited changes in winter weather phenomena had to do with decreasing winter snowfall, with 62.3 percent, 30.8 percent, and 43.9 percent of alpine wet meadow, alpine meadow, and alpine steppe dwelling respondents, respectively, citing decreasing winter snowfall as an impact of climate change, while majorities of respondents inhabiting all three types of grasslands cited an increase in high wind events during winter (Table 5.33).

5.4 Impacts of Climate Change on the Local Environment and Livestock Herding

In the second survey section, survey respondents were asked about aspects of the local environment affected by climate change, the harmful effects of climate change on the local environment, and both the positive and negative impacts of climate change on the local livestock industry.

5.4.1 Survey Question 7: In your opinion, what aspects of the local environment and ecology have been obviously affected by climate change?

Table 5.34 Aspects of the local environment and ecology obviously affected by climate change, all survey respondents

Aspects of the Environment and Ecology Affected by Climate Change	Number of Responses	Percentage of All Responses	Percentage of Survey Respondents
River Discharge Volume	78	14.7	39.0
Rodent Infestations	71	13.4	35.5
Forage Quality	70	13.2	35.0
Grasslands	53	10.0	26.5
Wind Intensity	45	8.5	22.5
Amount of Rainfall	43	8.1	21.5
Soil Erosion	28	5.3	14.0
Glacier and Snow Meltoff	27	5.1	13.5
Land Quality	25	4.7	12.5
Insect Pests	19	3.6	9.5
Pasturelands	18	3.4	9.0
Wild Animals	18	3.4	9.0
Water Quality	7	1.3	3.5
Lakes	7	1.3	3.5
Hail	5	0.9	2.5
Shrubs	1	0.2	0.5
Other	15	2.8	7.5
Total	530	100 %	N/A

Note: Survey respondents were permitted to cite up to three aspects. Percentages are based on 200 survey respondents.

Table 5.35 Aspects of the local environment and ecology obviously affected by climate change, by county

County	Zhidoi County		Chumarleb County	
Aspects of the Environment and Ecology Affected by Climate Change	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
River Discharge Volume	47	50.0	31	29.2
Rodent Infestations	31	33.0	40	37.7
Forage Quality	34	36.2	36	34.0
Grasslands	13	13.8	40	37.7
Wind Intensity	16	17.0	29	27.4
Amount of Rainfall	18	19.1	25	23.6
Soil Erosion	7	7.4	21	19.8
Glacier and Snow Meltoff	19	20.2	8	7.5
Land Quality	7	7.4	12	11.3
Insect Pests	11	11.7	8	7.5
Pasturelands	10	10.6	8	7.5
Wild Animals	13	13.8	5	4.7
Water Quality	9	9.6	4	3.8
Lakes	3	3.2	4	3.8
Hail	4	4.3	1	0.9
Shrubs	0	0	1	0.9
Other	6	6.4	1	0.9
Total	248	N/A	274	N/A

Note: Survey respondents were permitted to cite up to three aspects. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.36 Aspects of the local environment and ecology obviously affected by climate change, by occupation

Occupation	**Herders**		**Non-Herders**	
Aspects of the Environment and Ecology Affected by Climate Change	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
River Discharge Volume	63	47.4	15	22.4
Rodent Infestations	42	31.6	29	43.3
Forage Quality	54	40.6	16	23.9
Grasslands	36	27.1	17	25.4
Wind Intensity	38	28.6	7	10.4
Amount of Rainfall	33	24.8	10	14.9
Soil Erosion	4	3.0	24	35.8
Glacier and Snow Meltoff	11	8.3	16	23.9
Land Quality	12	9.0	7	10.4
Insect Pests	5	3.8	14	20.9
Pasturelands	15	11.3	3	4.5
Wild Animals	8	6.0	10	14.9
Water Quality	11	8.3	2	3.0
Lakes	7	5.3	0	0
Hail	4	3.0	1	1.5
Shrubs	0	0	1	1.5
Other	9	6.8	6	9.0
Total	352	N/A	178	N/A

Note: Survey respondents were permitted to cite up to three aspects. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.37 Aspects of the local environment and ecology obviously affected by climate change, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Aspects Ecology and Environ-ment Affected by Climate Change	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
River Discharge Volume	20	37.7	21	40.4	32	48.5
Rodent Infestations	11	20.8	20	38.5	24	36.4
Forage Quality	26	49.1	23	44.2	19	28.8
Grasslands	17	32.1	17	32.7	14	21.2
Wind Intensity	8	15.1	10	19.2	26	39.4
Amount of Rainfall	9	17.0	11	21.2	17	25.8
Soil Erosion	4	7.5	4	7.7	7	10.6
Glacier and Snow Meltoff	8	15.1	5	9.6	5	7.6
Land Quality	8	15.1	6	11.5	4	6.1
Insect Pests	0	0	8	15.4	2	3.0
Pasturelands	7	13.2	5	9.6	3	4.5
Wild Animals	5	9.4	1	1.9	7	10.6
Water Quality	7	13.2	2	3.8	4	6.1
Lakes	2	3.8	1	1.9	4	6.1
Hail	2	3.8	1	1.9	1	1.5
Shrubs	0	0	0	0	0	0
Other	4	7.5	1	1.9	9	13.6
Total	138	N/A	136	N/A	178	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three aspects. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

The most commonly cited aspects of the local environment and ecology obviously affected by climate change were river discharge volume (cited by 39 percent of all survey respondents), rodent infestations (35.5 percent of survey respondents), forage quality (35 percent of survey respondents) and grasslands (26.5 percent of survey respondents) (Table 5.34). Similar percentages of respondents from Zhidoi and Chumarleb Counties cited rodent infestations (33 and 37.7 percent, respectively) and forage quality (36.2 and 34 percent respectively) as

being affected by climate change. However, 50 percent of survey respondents from Zhidoi County cited river discharge volume versus 29.2 percent of respondents from Chumarleb County, while 13.8 percent of respondents from Zhidoi County cited grasslands versus 37.7 percent of respondents from Chumarleb County (Table 5.35). In terms of occupation, the most commonly stated aspects of ecology and the environment affected by climate change cited by herders were river discharge volume and forage quality, cited by 47.4 and 40.6 percent of surveyed herders, respectively, while amongst non-herders, the two most frequently cited aspects were rodent infestations and soil erosion, cited by 43.3 and 35.8 percent of surveyed non-herders, respectively (Table 5.36). With respect to type of grassland inhabited, residents of both alpine wet meadows and alpine meadows cited forage quality most frequently, as stated by 49.1 and 44.2 percent of these respondents, respectively (Table 5.37). However, river discharge volume was the aspect most frequently cited by inhabitants of alpine steppe, as stated by 48.5 percent of steppe-dwelling survey respondents (Table 5.37).

5.4.2 Survey Question 8: In your opinion, climate change has had what harmful effects on the local environment and ecology?

Table 5.38 Harmful effects of climate change on the local environment and ecology, all survey respondents

Harmful Effects of Climate Change on the Local Environment and Ecology	Number of Responses	Percentage of All Responses	Percentage of Survey Respondents
Decline in Grass Quality	110	20.9	55.0
Increase in Rodent Infestations	92	17.5	46.0
Desertification	72	13.7	36.0
Decrease in Area of Grasslands	55	10.4	27.5
Insufficient Rainfall	45	8.5	22.5
Decrease in River Discharge Volume	41	7.8	20.5
Increase in Soil Erosion	25	4.7	12.5
Decrease in Area of Pasturelands	23	4.4	11.5
Increase in Insect Pests	21	4.0	10.5
Temperatures Higher or Lower	13	2.5	6.5
Increase in Snow Disasters	12	2.3	6.0
Increase in Hailstorms	5	1.0	2.5
Decrease in Shrubs	1	0.2	0.5
Other	12	2.3	6.0
Total	527	100 %	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 200 survey respondents.

Table 5.39 Harmful effects of climate change on the local environment and ecology, by county

County	Zhidoi County		Chumarleb County	
Harmful Effects of Climate Change on the Local Environment and Ecology	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
Decline in Grass Quality	46	48.9	64	60.4
Increase in Rodent Infestations	37	39.4	55	51.9
Desertification	33	35.1	39	36.8
Decrease in Area of Grasslands	27	28.7	28	26.4
Insufficient Rainfall	28	29.8	17	16.0
Decrease in River Discharge Volume	17	18.1	24	22.6
Increase in Soil Erosion	12	12.8	13	12.3
Decrease in Area of Pasturelands	17	18.1	6	5.7
Increase in Insect Pests	12	12.8	9	8.5
Temperatures Higher or Lower	10	10.6	3	2.8
Increase in Snow Disasters	4	4.3	8	7.5
Increase in Hailstorms	2	2.1	3	2.8
Decrease in Shrubs	0	0	1	0.9
Other	6	6.4	6	5.7
Total	251	N/A	276	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.40 Harmful effects of climate change on the local environment and ecology, by occupation

Occupation	**Herders**		**Non-Herders**	
Harmful Effects of Climate Change on the Local Environment and Ecology	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
Decline in Grass Quality	79	59.4	31	46.3
Increase in Rodent Infestations	60	45.1	32	47.8
Desertification	35	26.3	37	55.2
Decrease in Area of Grasslands	33	24.8	22	32.8
Insufficient Rainfall	38	28.6	7	10.4
Decrease in River Discharge Volume	31	23.3	10	14.9
Increase in Soil Erosion	8	6.0	17	25.4
Decrease in Area of Pasturelands	13	9.8	10	14.9
Increase in Insect Pests	9	6.8	12	17.9
Temperatures Higher or Lower	12	9.0	1	1.5
Increase in Snow Disasters	7	5.3	5	7.5
Increase in Hailstorms	2	1.5	3	4.5
Decrease in Shrubs	0	0	1	1.5
Other	11	8.3	1	1.5
Total	338	N/A	189	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.41 Harmful effects of climate change on the local environment and ecology, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Harmful Effects of Climate Change on the Local Environment and Ecology	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
Decline in Grass Quality	36	67.9	26	50.0	33	50.0
Increase in Rodent Infestations	16	30.2	25	48.1	35	53.0
Desertification	10	18.9	13	25.0	29	43.9
Decrease in Area of Grasslands	11	20.8	11	21.2	27	40.9
Insufficient Rainfall	14	26.4	12	23.1	19	28.8
Decrease in River Discharge Volume	13	24.5	11	21.2	14	21.2
Increase in Soil Erosion	6	11.3	4	7.7	6	9.1
Decrease in Area of Pasturelands	13	24.5	3	5.8	5	7.6
Increase in Insect Pests	3	5.7	11	21.2	1	1.5
Temperatures Higher or Lower	9	17.0	2	3.8	2	3.0
Increase in Snow Disasters	1	1.9	6	11.5	4	6.1
Increase in Hailstorms	2	3.8	0	0	0	0
Decrease in Shrubs	0	0	0	0	0	0
Other	4	7.5	4	7.7	4	6.1
Total	138	N/A	128	N/A	179	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three effects. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

Survey respondents cited a wide range of negative effects of climate change on the local environment and ecology, however, the four most commonly cited effects were a decline in grass quality (55 percent of all survey respondents), an increase in the occurrence of rodent infestations (46 percent of survey respondents),

desertification (36 percent of survey respondents), and a decrease in the area of grasslands suitable for grazing (27.5 percent of survey respondents) (Table 5.38). Responses to this question were similar in both Zhidoi and Chumarleb Counties, although higher percentages of respondents in Chumarleb County cited a decline in grass quality and an increase in rodent infestations (60.4 and 51.9 percent, respectively) than in Zhidoi County (48.9 and 39.4 percent, respectively), while far more survey respondents in Zhidoi County cited insufficient rainfall (29.8 percent) than in Chumarleb County (16 percent) (Table 5.39). In terms of occupation, a decline in grass quality was the harmful effect of climate change most commonly cited by herders (59.4 percent versus 46.3 percent of non-herders), while at 55.2 percent, desertification was the effect most commonly cited by non-herders, who cited this effect over twice as often as herders (26.3 percent) (Table 5.40). In terms of the type of grassland occupied, 67.9 percent of inhabitants of alpine wet meadows cited a decline in grass quality as a harmful effect of climate change versus 50 percent of survey respondents inhabiting both alpine meadow and alpine steppe grasslands who cited this effect (Table 5.41). Notably, increasing rodent infestations and desertification were cited at a much higher rate by alpine steppe dwellers (53 and 43.9 percent, respectively), than by either alpine meadow dwellers (48.1 and 25 percent, respectively) or alpine wet meadow inhabitants (30.2 and 18.9 percent, respectively) (Table 5.41).

5.4.3 Survey Question 9: In your opinion, climate change has had what positive effects on the local livestock industry?

Table 5.42 Positive effects of climate change on the local livestock industry, all survey respondents

Positive Effects of Climate Change on the Local Environment and Ecology	**Number of Responses**	**Percentage of All Responses**	**Percentage of Survey Respondents**
No Positive Effects	114	36.4	57
Improvement in Forage Quality	35	11.2	17.5
Conditions for Raising Livestock are Improving Regarding Water and Grass Availability	28	8.9	14
Climate for Raising Livestock is More Suitable	27	8.6	13.5
Decrease in Insect and Rodent Infestations	16	5.1	8
Decrease in Livestock Disease	11	3.5	5.5
Increase in Area of Pasturelands	7	2.2	3.5
Local Livestock Breeds are More Suitable	7	2.2	3.5
Decrease in Harm Caused by Wild Animals	7	2.2	3.5
Local Livestock Numbers are More Suitable	6	1.9	3
Increase in Shrubs	4	1.3	2
Other	51	16.3	25.5
Total	313	100 %	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 200 survey respondents.

The majority of survey respondents, 57 percent, simply stated that there were no positive effects of climate change on the local livestock industry (Table 5.42). The remaining 43 percent of survey respondents cited a wide and inconclusive variety of positive effects of climate change, the most commonly cited of which were improved quality of forage, improved conditions for raising livestock with respect to grass and water availability, and the climate for raising livestock is more suitable, which were cited by just 17.5, 14, and 13.5 percent of survey respondents, respectively (Table 5.42).

5.4.4 Survey Question 10: In your opinion, climate change has had what harmful effects on the local livestock industry?

Table 5.43 Harmful effects of climate change on the local livestock industry, all survey respondents

Harmful Effects of Climate Change on the Local Livestock Industry	Number of Responses	Percentage of All Responses	Percentage of Survey Respondents
Decline in Forage Quality	86	15.7	43.0
Increase in Insect and Rodent Infestations	81	14.8	40.5
Increase in Livestock Disease	59	10.8	29.5
Conditions for Raising Livestock are Worsening Regarding Water and Grass Availability	54	9.9	27.0
Climate for Raising Livestock is Worsening	48	8.8	24.0
Desertification of Pasturelands	46	8.4	23.0
Decline in Groundwater Reserves in Pasture Areas	39	7.1	19.5
“Black Beach” Areas Increasing*	32	5.8	16.0
Decrease in Area of Pasturelands	28	5.1	14.0
Pasture Degradation	27	4.9	13.5
Qualitative Change in Grass Species	22	4.0	11.0
Livestock Breeds are Unsuitable	6	1.1	3.0
Decrease in Shrubs	4	0.7	2.0
Livestock Numbers are Too High	3	0.6	1.5
Other	13	2.4	6.5
Total	548	100 %	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 200 survey respondents.
* “Black Beach” is a local term for large patches of former grassland that have been completely denuded of grass and had their soil structure destroyed, leaving only loose topsoil and sand.

Table 5.44 Harmful effects of climate change on the local livestock industry, by county

County	**Zhidoi County**		**Chumarleb County**	
Harmful Effects of Climate Change on the Local Livestock Industry	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
Decline in Forage Quality	35	37.2	51	48.1
Increase in Insect and Rodent Infestations	28	29.8	53	50.0
Increase in Livestock Disease	33	35.1	26	24.5
Conditions for Raising Livestock are Worsening Regarding Water and Grass Availability	21	22.3	33	31.1
Climate for Raising Livestock is Worsening	34	36.2	14	13.2
Desertification of Pasturelands	16	17.0	30	28.3
Decline in Groundwater Reserves in Pasture Areas	25	26.6	14	13.2
“Black Beach” Areas Increasing	9	9.6	23	21.7
Decrease in Area of Pasturelands	21	22.3	7	6.6
Pasture Degradation	9	9.6	18	17.0
Qualitative Change in Grass Species	11	11.7	11	10.4
Livestock Breeds are Unsuitable	5	5.3	1	0.9
Decrease in Shrubs	4	4.3	0	0
Livestock Numbers are Too High	2	2.1	1	0.9
Other	5	5.3	8	7.5
Total	258	N/A	290	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.45 Harmful effects of climate change on the local livestock industry, by occupation

Occupation	**Herders**		**Non-Herders**	
Harmful Effects of Climate Change on the Local Livestock Industry	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
Decline in Forage Quality	65	48.9	21	31.3
Increase in Insect and Rodent Infestations	49	36.8	32	47.8
Increase in Livestock Disease	42	31.6	17	25.4
Conditions for Raising Livestock are Worsening Regarding Water and Grass Availability	41	30.8	13	19.4
Climate for Raising Livestock is Worsening	45	33.8	3	4.5
Desertification of Pasturelands	21	15.8	25	37.3
Decline in Groundwater Reserves in Pasture Areas	28	21.1	11	16.4
“Black Beach” Areas Increasing	12	9.0	20	29.9
Decrease in Area of Pasturelands	21	15.8	7	10.4
Pasture Degradation	13	9.8	14	20.9
Qualitative Change in Grass Species	11	8.3	11	16.4
Livestock Breeds are Unsuitable	4	3.0	2	3.0
Decrease in Shrubs	1	0.8	3	4.5
Livestock Numbers are Too High	1	0.8	2	3.0
Other	12	9.0	1	1.5
Total	366	N/A	182	N/A

Note: Survey respondents were permitted to cite up to three effects. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.46 Harmful effects of climate change on the local livestock industry, by type of grassland inhabited

Grassland Type	Alpine Wet Meadow		Alpine Meadow		Alpine Steppe	
Harmful Effects of Climate Change on the Local Livestock Industry	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
Decline in Forage Quality	24	45.3	22	42.3	33	50.0
Increase in Insect and Rodent Infestations	14	26.4	25	48.1	26	39.4
Increase in Livestock Disease	19	35.8	15	28.8	18	27.3
Conditions for Raising Livestock are Worsening Regarding Water and Grass Availability	17	32.1	16	30.8	18	27.3
Climate for Raising Livestock is Worsening	14	26.4	8	15.4	25	37.9
Desertification of Pasturelands	6	11.3	9	17.3	20	30.3
Decline in Groundwater Reserves in Pasture Areas	7	13.2	12	23.1	17	25.8
"Black Beach" Areas Increasing	3	5.7	11	21.2	5	7.8
Decrease in Area of Pasturelands	15	28.3	6	11.5	6	9.1
Pasture Degradation	8	15.1	4	7.7	8	12.1
Qualitative Change in Grass Species	6	11.3	6	11.5	4	6.1
Livestock Breeds are Unsuitable	4	7.5	2	3.8	0	0
Decrease in Shrubs	0	0	1	1.9	0	0
Livestock Numbers are Too High	1	1.9	0	0	1	1.5
Other	7	13.2	2	3.8	4	6.1
Total	145	N/A	139	N/A	185	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three effects. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

Livestock herding is the primary economic activity of the Yangtze Source Region. Therefore, it is important to assess the views of the region's residents on the negative impacts climate change has had on the local livestock industry. The most commonly cited negative impacts of climate change on the local livestock industry were a decline in forage quality, cited by 43 percent of all survey respondents; an increase in the occurrence of rodent and insect infestations, cited by 40.5 percent of respondents; an increase in livestock disease, cited by 29.5 percent of respondents; and a worsening of conditions for livestock raising with respect to water and grass availability, cited by 27 percent of survey respondents (Table 5.43).

In Zhidoi County, the most common responses to this question were a decline in forage quality, a worsening of the climate with regard to raising livestock, and an increase in livestock disease, cited by 37.2, 36.2, and 35.1 percent of survey respondents from Zhidoi County, respectively. These responses were only marginally higher than for an increase in insect and rodent infestations, which was cited by 29.8 percent of respondents from Zhidoi (Table 5.44). In Chumarleb County, the most commonly cited harmful effects of climate change on livestock herding were increases in insect and rodent infestations, a decline in forage quality, and a worsening of conditions for raising livestock with respect to water and grass availability, as cited by 50, 48.1, and 31.1 percent of Chumarleb County survey respondents, respectively. A close fourth response was desertification of pasturelands, which was cited by 28.3 percent of respondents from Chumarleb County (Table 5.44).

Amongst herders, the most common responses to this question were a decline in forage quality, an increase in the incidence of insect and rodent infestations, and a worsening of the climate with regard to raising livestock, cited by 48.9, 36.8, and 33.8 percent of surveyed herders, respectively, responses which were followed closely by an increase in livestock disease (31.6 percent of surveyed herders) and worsening of conditions for livestock with respect to water and grass availability (30.8 percent of surveyed herders) (Table 5.45). Amongst non-herders, the most commonly cited harmful effects of climate change on the livestock industry were increases in insect and rodent infestations, desertification of pasturelands, and a decline in forage quality, cited by 47.8, 37.3, and 31.3 percent of surveyed non-herders, respectively (Table 5.45). These responses were followed closely by an increase in "black beach" areas, which was cited as a harmful effect of climate change by 29.9 percent of non-herders, although, notably, this phenomena was only cited by 9 percent of herders (Table 5.45).

In terms of the type of grassland inhabited, residents of alpine wet meadows cited a decline in forage quality, an increase in livestock disease, and worsening of conditions for raising livestock with respect to water and grass availability as the three most harmful effects of climate change, with 45.3, 35.8, and 32.1 percent of surveyed wet meadow residents, respectively (Table 5.46). Residents of alpine meadows most frequently cited an increase in insect and rodent infestations, a decline in forage quality, and a worsening of conditions for raising livestock with respect to water and grass availability, with 48.1, 42.3, and 30.8 percent of surveyed alpine meadow residents, respectively (Table 5.46). Amongst alpine steppe dwellers, the most frequently cited harmful effects of climate change were a decline in forage quality, an increase in insect and rodent infestations, and a worsening of the climate with respect to raising livestock, as cited by 50, 39.4, and 37.9 percent of surveyed alpine steppe residents, respectively (Table 5.46). Notably, 30.3 percent of alpine steppe inhabitants cited desertification of pasturelands as a harmful effect of climate change on the local livestock industry, as opposed to just 17.3 and 11.3 percent of surveyed alpine meadow and alpine wet meadow residents, respectively (Table 5.46).

5.5 The Impact of Climate Change on Grassland Degradation and Desertification

In the third survey section, survey respondents were asked their opinions on the degree of the relationship between grassland degradation and climate change, the degree of seriousness of the local grassland degradation and desertification problems, the timing of grassland degradation and desertification, and the root causes of these problems.

5.5.1 Survey Question 11: In your opinion, is there a relationship between local climate change and the appearance of grassland degradation or desertification ("black beach") problems?

Table 5.47 Degree of relationship between local climate change and the problem of grassland degradation or desertification, all survey respondents

Degree of Relationship between Climate Change and Grassland Degradation/Desertification	Number of Survey Respondents	Percentage of Survey Respondents
Very Close Relationship	122	61.0
Fairly Close Relationship	63	31.5
Small Relationship	14	7.0
Don't Know	1	0.5
Total	200	100 %

Table 5.48 Degree of relationship between local climate change and the problem of grassland degradation or desertification, by county

County	Zhidoi County		Chumarleb County	
Degree of Relationship between Climate Change and Grassland Degradation/ Desertification	Number of Surveyed Zhidoi County Residents	Percentage of Surveyed Zhidoi County Residents	Number of Surveyed Chumarleb County Residents	Percentage of Surveyed Chumarleb County Residents
Very Close Relationship	53	56.4	69	65.1
Fairly Close Relationship	35	37.2	28	26.4
Small Relationship	5	5.3	9	8.5
Don't Know	1	1.1	0	0.0
Total	94	100 %	106	100 %

Table 5.49 Degree of relationship between local climate change and the problem of grassland degradation or desertification, by occupation

Occupation	**Herders**		**Non-Herders**	
Degree of Relationship between Climate Change and Grassland Degradation/ Desertification	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Very Close Relationship	87	65.4	35	52.2
Fairly Close Relationship	34	25.6	29	43.3
Small Relationship	11	8.3	3	4.5
Don't Know	1	0.8	0	0
Total	133	100 %	67	100 %

Table 5.50 Degree of relationship between local climate change and the problem of grassland degradation or desertification, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Degree of Relationship between Climate Change and Grassland Degradation/ Desertification	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Very Close Relationship	31	58.5	29	55.8	46	69.7
Fairly Close Relationship	16	30.2	17	32.7	17	25.8
Small Relationship	6	11.3	5	9.6	3	4.6
Don't Know	0	0	1	1.9	0	0
Total	53	100 %	52	100 %	66	100

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of the 200 survey respondents, a full 92.5 percent stated that they believed climate change and the problems of grassland degradation and desertification in the Yangtze Source Region were either "fairly closely" related (31.5 percent of survey respondents) or "very closely" related (61 percent of survey respondents) (Table 5.47). By county, 37.2 and 56.4 percent of residents of Zhidoi County felt there was a "fairly close" or "very close" relationship between climate change and grassland degradation or desertification, respectively, while 26.4 and 65.1 percent of residents of Chumarleb County felt there was either a "fairly close" or "very close" relationship, respectively (Table 5.48). With respect to occupation, 25.6 and 65.4 percent of surveyed herders felt there was either a "fairly close" or "very close" relationship between climate change and grassland degradation or desertification,

respectively, as compared to 43.3 and 52.2 percent of non-herders who felt there was either a "fairly close" or "very close" relationship between these issues, respectively (Table 5.49). Responses as tallied by the type of grassland inhabited were similar, with 30.2 and 58.5 percent of alpine wet meadow respondents, 32.7 and 55.8 percent of alpine meadow respondents, and 25.8 and 69.7 percent of steppe-dwelling survey respondents stating that there was either a "fairly close" or "very close" relationship, respectively, between climate change and grassland degradation and desertification (Table 5.50).

5.5.2 Survey Question 12: In your opinion, what is the degree of the local problem of grassland degradation or desertification?

Table 5.51 Degree of the local problem of grassland degradation or desertification, all respondents

Degree of Grassland Degradation/Desertification Problem	Number of Survey Respondents	Percentage of Survey Respondents
Very Serious	105	52.5
Fairly Serious	68	34.0
Somewhat Serious	17	8.5
Not Serious	5	2.5
Hasn't Occurred	5	2.5
Total	200	100 %

Table 5.52 Degree of the local problem of grassland degradation or desertification, by county

County	**Zhidoi County**		**Chumarleb County**	
Degree of Grassland Degradation/ Desertification Problem	**Number of Surveyed Zhidoi County Residents**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Surveyed Chumarleb County Residents**	**Percentage of Surveyed Chumarleb County Residents**
Very Serious	31	33.0	74	69.8
Fairly Serious	40	42.6	28	26.4
Somewhat Serious	15	16.0	2	1.9
Not Serious	4	4.3	1	0.9
Hasn't Occurred	4	4.3	1	0.9
Total	94	100 %	106	100 %

Table 5.53 Degree of the local problem of grassland degradation or desertification, by occupation

Occupation	**Herders**		**Non-Herders**	
Degree of Grassland Degradation/ Desertification Problem	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Percentage of Surveyed Herders**	**Percentage of Surveyed Non-Herders**
Very Serious	71	53.4	34	50.8
Fairly Serious	44	33.1	24	35.8
Somewhat Serious	9	6.8	8	11.9
Not Serious	4	3.0	1	1.5
Hasn't Occurred	5	3.8	0	0.0
Total	133	100 %	67	100 %

Table 5.54 Degree of the local problem of grassland degradation or desertification, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Degree of Grassland Degradation/ Desertification Problem	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Very Serious	24	45.3	30	57.7	40	60.6
Fairly Serious	21	39.6	16	30.8	17	25.8
Somewhat Serious	2	3.8	5	9.6	6	9.1
Not Serious	4	7.6	0	0.0	1	1.5
Hasn't Occurred	2	3.8	1	1.9	2	3.0
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of 200 survey respondents, 86.5 percent stated that they felt that the local problem of grassland degradation or desertification in the surveyed area of the Yangtze Source Region was either "fairly serious" (34 percent of survey respondents) or "very serious" (52.5 percent of survey respondents) (Table 5.51). In Chumarleb County, 69.8 percent of surveyed residents felt that there was a "very serious" problem of grassland degradation or desertification versus just 33 percent of surveyed residents in Zhidoi County (Table 5.52). At the same time, 26.4 and 42.6 percent of surveyed residents in Chumarleb and Zhidoi Counties, respectively, stated that grassland degradation and desertification were "fairly serious" problems (Table 5.52). By occupation, there was remarkably close correlation in opinions on the severity of the grassland degradation or desertification problem, with 53.4 and 50.8 percent of herders and non-herders, respectively, stating that these problems were "very serious," while 33.1 and 35.8 percent of herders and non-herders,

respectively, stated that these problems were "fairly serious" (Table 5.53). In terms of the type of grassland occupied, 60.6 and 57.7 percent of surveyed residents of alpine steppe and alpine meadows, respectively, felt grassland degradation and desertification were "very serious" problems versus a smaller percentage of surveyed alpine wet meadow dwellers, 45.3 percent of whom felt these problems were "very serious" (Table 5.54).

5.5.3 Survey Question 13: In your opinion, when did the problem of grassland degradation or desertification begin to occur?

Table 5.55 Period of occurrence of onset of grassland degradation or desertification, all survey respondents

Onset of Grassland Degradation or Desertification	Number of Survey Respondents	Percentage of Survey Respondents
Before 1950	1	0.5
1950-1969	1	0.5
1970-1979	4	2.0
1980-1989	76	38.0
1990-1999	49	24.5
2000-2005	60	30.0
Hasn't Occurred	9	4.5
Total	200	100 %

Table 5.56 Period of occurrence of onset of grassland degradation or desertification, by county

County	Zhidoi County		Chumarleb County	
Onset of Grassland Degradation or Desertification	**Number of Surveyed Zhidoi County Residents**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Surveyed Chumarleb County Residents**	**Percentage of Surveyed Chumarleb County Residents**
Before 1950	0	0.0	1	0.9
1950-1969	1	1.1	0	0.0
1970-1979	2	2.1	2	1.9
1980-1989	39	41.5	37	34.9
1990-1999	14	14.9	35	33.0
2000-2005	31	33.0	29	27.4
Hasn't Occurred	7	7.5	2	1.9
Total	94	100 %	106	100 %

Table 5.57 Period of occurrence of onset of grassland degradation or desertification, by occupation

Occupation	Herders		Non-Herders	
Onset of Grassland Degradation or Desertification	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Before 1950	1	0.8	0	0.0
1950-1969	1	0.8	0	0.0
1970-1979	2	1.5	2	3.0
1980-1989	53	39.9	23	34.3
1990-1999	25	18.8	24	35.8
2000-2005	42	31.6	18	26.9
Hasn't Occurred	9	6.8	0	0.0
Total	133	100 %	67	100 %

Table 5.58 Period of occurrence of onset of grassland degradation or desertification, by type of grassland inhabited

Grassland Type	Alpine Wet Meadow		Alpine Meadow		Alpine Steppe	
Onset of Grassland Degradation or Desertification	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Before 1950	0	0.0	0	0.0	1	1.5
1950-1969	0	0.0	0	0.0	1	1.5
1970-1979	0	0.0	3	5.8	0	0.0
1980-1989	18	34.0	16	30.8	32	48.5
1990-1999	11	20.8	13	25.0	12	18.2
2000-2005	20	37.7	18	34.6	17	25.8
Hasn't Occurred	4	7.6	2	3.9	3	4.6
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of the 200 survey respondents, 92.5 percent stated that local grassland degradation and desertification in the Yangtze Source Region began between 1980 and 2005, with 38 percent of survey respondents stating that these problems began during the 1980s, 24.5 percent stating that these problems began in the 1990s, and 30 percent stating that these problems began between 2000 and 2005 (Table 5.55). The largest share of survey respondents in Zhidoi and Chumarleb Counties, 41.5 and 34.9 percent, respectively, stated that grassland degradation or desertification began during the 1980s (Table 5.56). Responses by occupation closely mirrored county totals, with 39.9 and 34.3 percent of herders and non-herders, respectively, being of the opinion that grassland degradation and desertification problems first began in the 1980s (Table 5.57). However, the largest share of non-herders, 35.8

percent, felt that these problems had first begun during the 1990s, in comparison to just 18.8 percent of herders who cited the 1990s as the beginning point of local grassland degradation or desertification (Table 5.57). Notably, in terms of the type of grassland inhabited, the largest share of surveyed alpine steppe inhabitants surveyed, 48.5 percent, felt that local grassland degradation and desertification problems first began in the 1980s, while in contrast, the largest shares of surveyed alpine wet meadow and alpine meadow residents, 37.7 and 34.6 percent, respectively, felt that these issues first arose between 2000 and 2005 (Table 5.58).

5.5.4 Survey Question 14: In your opinion, what are the main causes of grassland degradation or desertification?

Table 5.59 Causes of grassland degradation or desertification, all survey respondents

Causes of Grassland Degradation or Desertification	**Number of Responses**	**Percentage of All Responses**	**Percentage of Survey Respondents**
Climate Change	130	26.9	65.0
Appearance of Rodent Infestations on Grasslands	106	22.0	53.0
Opening of too Many Mines	60	12.4	30.0
Decreasing Availability of Water Resources	51	10.6	25.5
Natural Decreases in Area of Grasslands	19	3.9	9.5
Degradation of Grass Species	19	3.9	9.5
Division of Pastures amongst Households	12	2.5	6.0
Appearance of Plant Diseases and Insect Pests	18	3.7	9.0
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)*	13	2.7	6.5
Inappropriate Herding Methods	13	2.7	6.5
Human Population Increase	7	1.5	3.5
Livestock Numbers too High	7	1.5	3.5
4 and 7 Complete Sets Government Programs**	7	1.5	3.5
Inappropriate Government Policies	3	0.6	1.5
Other	18	3.7	9.0
Total	483	100 %	N/A

Note: Survey respondents were permitted to cite up to three causes. Percentages are based on 200 survey respondents.

* Caterpillar fungus (*Cordyceps sinensis*) is a valuable medicinal plant used in traditional Chinese and Tibetan medicine that grows in grassland topsoils and currently sells for about US $10,000/kg.

** The "Four Complete Sets" Program was initiated by the Chinese central government in the late 1990s and encourages western China's livestock herders to 1) fence off their household pastures, 2) grow hay for winter forage, 3) build winter livestock sheds, and 4) build houses for themselves. Likewise, the "Seven Complete Sets" Program promotes the previous four activities with the addition of 5) the use of wells as a source of safe drinking water, 6) the use of solar and other low power electricity systems, and 7) the building of roads to improve transportation and access to markets.

Table 5.60 Causes of grassland degradation or desertification, by county

County	**Zhidoi County**		**Chumarleb County**	
Causes of Grassland Degradation or Desertification	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
Climate Change	61	64.9	69	65.1
Appearance of Rodent Infestations on Grasslands	33	35.1	73	68.9
Opening of too Many Mines	32	34.0	28	26.4
Decreasing Availability of Water Resources	20	21.3	31	29.2
Natural Decreases in Area of Grasslands	11	11.7	8	7.5
Degradation of Grass Species	9	9.6	10	9.4
Division of Pastures amongst Households	9	9.6	3	2.8
Appearance of Plant Diseases and Insect Pests	8	8.5	10	9.4
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	2	2.1	11	10.4
Inappropriate Herding Methods	8	8.5	5	4.7
Human Population Increase	5	5.3	2	1.9
Livestock Numbers too High	0	0	7	6.6
4 and 7 Complete Sets Government Programs	7	7.4	0	0
Inappropriate Government Policies	3	3.2	0	0
Other	9	9.6	9	8.5
Total	217	N/A	266	N/A

Note: Survey respondents were permitted to cite up to three causes. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.61 Causes of grassland degradation or desertification, by occupation.

Occupation	**Herders**		**Non-Herders**	
Causes of Grassland Degradation or Desertification	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
Climate Change	99	74.4	31	46.3
Appearance of Rodent Infestations on Grasslands	70	52.6	36	53.7
Opening of too Many Mines	33	24.8	27	40.3
Decreasing Availability of Water Resources	32	24.1	19	28.4
Natural Decreases in Area of Grasslands	14	10.5	5	7.5
Degradation of Grass Species	8	6.0	11	16.4
Division of Pastures amongst Households	6	4.5	6	9.0
Appearance of Plant Diseases and Insect Pests	10	7.5	8	11.9
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	2	1.5	11	16.4
Inappropriate Herding Methods	7	5.3	6	9.0
Human Population Increase	2	1.5	5	7.5
Livestock Numbers too High	1	0.8	6	9.0
4 and 7 Complete Sets Government Programs	3	2.3	4	6.0
Inappropriate Government Policies	2	1.5	1	1.5
Other	17	12.8	1	1.5
Total	306	N/A	177	N/A

Note: Survey respondents were permitted to cite up to three causes. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.62 Causes of grassland degradation or desertification, by type of grassland inhabited.

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Causes of Grassland Degradation or Desertification	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
Climate Change	39	73.6	31	59.6	49	74.2
Appearance of Rodent Infestations on Grasslands	25	47.2	30	57.7	36	54.5
Opening of too Many Mines	15	28.3	14	26.9	19	28.8
Decreasing Availability of Water Resources	10	18.9	13	25.0	19	28.8
Natural Decreases in Area of Grasslands	6	11.3	4	7.7	6	9.1
Degradation of Grass Species	2	3.8	7	13.4	4	6.1
Division of Pastures amongst Households	2	3.8	3	5.8	3	4.5
Appearance of Plant Diseases and Insect Pests	1	1.9	8	15.4	3	4.5
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	2	3.8	0	0	6	9.1
Inappropriate Herding Methods	1	1.9	6	11.5	3	4.5
Human Population Increase	1	1.9	1	1.9	2	3.0
Livestock Numbers too High	0	0	4	7.7	0	0
4 and 7 Complete Sets Government Programs	2	3.8	2	3.8	2	3.0
Inappropriate Government Policies	2	3.8	1	1.9	0	0
Other	10	18.9	3	5.8	5	7.6
Total	118	N/A	127	N/A	157	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three causes. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

The top four causes of grassland degradation or desertification in the Yangtze Source Region cited by survey respondents were climate change (65 percent of all respondents), rodent infestations (53 percent of respondents), mining (30 percent of respondents), and decreasing availability of water supplies (25.5 percent of respondents) (Table 5.59). Notably, livestock numbers being too high, which results in the overgrazing that is perhaps the primary cause of pasture degradation and desertification in the Yangtze Source Region (see Chapter 2 of this report), ranked twelfth of fourteen possible responses to this question, only having been cited by 3.5 percent of all survey respondents (Table 5.59). Climate change was cited as a cause of grassland degradation or desertification by similar numbers of Zhidoi and Chumarleb County survey respondents, 64.9 and 65.1 percent, respectively (Table 5.60). However, the most frequently cited cause of grassland degradation or desertification in Chumarleb County was rodent infestations, cited by 68.9 percent of Chumarleb County survey respondents, versus just 35.1 percent of Zhidoi County residents who cited this cause (Table 5.60). But as discussed in Chapter 2 of this report, rodent infestations may largely be a result of chronic overgrazing, not climate change. In terms of occupation, the most frequently cited cause of grassland degradation or desertification amongst surveyed herders was climate change, cited by 74.4 percent of herders versus 46.3 percent of surveyed non-herders who cited this cause (Table 5.61). The most frequently cited cause of these grassland issues amongst non-herders was rodent infestations (53.7 percent of surveyed non-herders) versus 52.6 percent of herders who cited this cause (Table 5.61). Regardless of grassland type, climate change followed by rodent infestations were the two leading causes of grassland degradation or desertification cited by grassland dwellers, with climate change having been cited by 73.6, 59.6, and 74.2 percent of alpine wet meadow, alpine meadow, and alpine steppe inhabitants, respectively, while rodent infestations were cited by 47.2, 57.7 and 54.5 percent of these grassland inhabitants, respectively (Table 5.62).

5.6 The Impact of Climate Change on the Decline in Area of Grasslands Suitable for Livestock Grazing.

In the fourth survey section, survey respondents were asked their opinions on the degree of the relationship between climate change and the decline in area of grasslands suitable for grazing livestock, the degree of seriousness of the local problem of pasture area decline, the timing of the onset of pasture area decline, and the root causes of this problem.

5.6.1 Survey Question 15: In your opinion, is there a relationship between local climate change and the decline in area of grasslands or pastures?

Table 5.63 Degree of relationship between climate change and the decline in area of grasslands and pastures, all survey respondents

Degree of Relationship between Climate Change and Decreasing Area of Grasslands and Pastures	Number of Survey Respondents	Percentage of Survey Respondents
Very Close Relationship	105	52.5
Fairly Close Relationship	74	37.0
Small Relationship	19	9.5
Don't Know	2	1.0
Total	200	100 %

Table 5.64 Degree of relationship between climate change and the decline in area of grasslands and pastures, by county

County	Zhidoi County		Chumarleb County	
Degree of Relationship between Climate Change and Decreasing Area of Grasslands and Pastures	**Number of Surveyed Zhidoi County Residents**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Surveyed Chumarleb County Residents**	**Percentage of Surveyed Chumarleb County Residents**
Very Close Relationship	46	48.9	59	55.7
Fairly Close Relationship	34	36.2	40	37.7
Small Relationship	13	13.8	6	5.7
Don't Know	1	1.1	1	0.9
Total	94	100 %	106	100 %

Table 5.65 Degree of relationship between climate change and the decline in area of grasslands and pastures, by occupation

Occupation	Herders		Non-Herders	
Degree of Relationship between Climate Change and Decreasing Area of Grasslands and Pastures	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Very Close Relationship	79	59.4	26	38.8
Fairly Close Relationship	42	31.6	32	47.8
Small Relationship	10	7.5	9	13.4
Don't Know	2	1.5	0	0.0
Total	133	100 %	67	100 %

Table 5.66 Degree of relationship between climate change and the decline in area of grasslands and pastures, by type of grassland inhabited

Grassland Type	Alpine Wet Meadow		Alpine Meadow		Alpine Steppe	
Degree of Relationship between Climate Change and Decreasing Area of Grasslands and Pastures	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Very Close Relationship	30	56.6	24	46.2	42	63.6
Fairly Close Relationship	19	35.9	21	40.4	19	28.8
Small Relationship	4	7.6	5	9.6	5	7.6
Don't Know	0	0.0	2	3.9	0	0.0
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Of 200 survey respondents, 89.5 percent felt that there was either a "fairly close" (37 percent) or "very close" (52.5 percent) relationship between climate change and decreasing area of pastures and grasslands suitable for grazing livestock (Table 5.63). County results closely mirror those for the whole survey, with 36.2 and 37.7 percent of surveyed residents of Zhidoi and Chumarleb Counties, respectively, feeling that there is a "fairly close" relationship between climate change and decreasing area of pastures and grasslands, while 48.9 and 55.7 percent of surveyed residents of Zhidoi and Chumarleb, respectively, felt that there is a "very close"

relationship (Table 5.64). Herders felt there was a closer relationship between these two issues than non-herders, with 59.4 percent of surveyed herders citing a "very close" relationship between climate change and decreasing area of pastures and grasslands, while only 38.8 percent of non-herders saw a "very close" relationship between these issues (Table 5.65). Amongst inhabitants of alpine steppe, 63.6 percent of those surveyed cited a "very close" relationship between climate change and decreasing area of pastures and grasslands versus 56.6 and 46.2 percent of surveyed inhabitants of alpine wet meadows and alpine meadows, respectively, who noted a "very close" relationship between these issues (Table 5.66).

5.6.2 Survey Question 16: In your opinion, what is the degree of the local problem of the decline in area of grasslands or pastures?

Table 5.67 Degree of the local problem of decline in area of grasslands or pastures, all survey respondents

Degree of Grassland and Pasture Area Decline Problem	Number of Survey Respondents	Percentage of Survey Respondents
Very Serious	88	44.0
Fairly Serious	76	38.0
Somewhat Serious	24	12.0
Not Serious	8	4.0
Hasn't Occurred	4	2.0
Total	200	100 %

Table 5.68 Degree of the local problem of decline in area of grasslands or pastures, by county

County	Zhidoi County		Chumarleb County	
Degree of Grassland and Pasture Area Decline Problem	**Number of Surveyed Zhidoi County Residents**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Surveyed Chumarleb County Residents**	**Percentage of Surveyed Chumarleb County Residents**
Very Serious	35	37.2	53	50.0
Fairly Serious	35	37.2	41	38.7
Somewhat Serious	15	16.0	9	8.5
Not Serious	6	6.4	2	1.9
Hasn't Occurred	3	3.2	1	0.9
Total	94	100 %	106	100 %

Table 5.69 Degree of the local problem of decline in area of grasslands or pastures, by occupation

Occupation	**Herders**		**Non-Herders**	
Degree of Grassland and Pasture Area Decline Problem	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Very Serious	66	49.6	22	32.8
Fairly Serious	49	36.8	27	40.3
Somewhat Serious	9	6.8	15	22.4
Not Serious	6	4.5	2	3.0
Hasn't Occurred	3	2.3	1	1.5
Total	133	100 %	67	100 %

Table 5.70 Degree of the local problem of decline in area of grasslands or pastures, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Degree of Grassland and Pasture Area Decline Problem	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Very Serious	22	41.5	29	55.8	30	45.5
Fairly Serious	22	41.5	17	32.7	25	37.9
Somewhat Serious	5	9.4	5	9.6	6	9.1
Not Serious	3	5.7	1	1.9	2	3.0
Hasn't Occurred	1	1.9	0	0	3	4.6
Total	53	100 %	52	100 %	66	100 %

Of 200 survey respondents, 82 percent felt that the problem of the decline in area of grasslands and pastures suitable for grazing livestock was either "fairly serious" (38 percent) or "very serious" (44 percent) (Table 5.67). Fifty percent of respondents from Chumarleb County felt this issue was "very serious," while 38.7 percent stated that this problem was "fairly serious" (Table 5.68). Equal numbers of Zhidoi County respondents, 37.2 percent, stated that the problem of the decline in area of grasslands or pastures was either "fairly serious" or "very serious" (Table 5.68). A much larger proportion of herders viewed the problem as being "very serious" (49.6 percent), than did non-herders (32.8 percent) (Table 5.69). In terms of the type of grassland inhabited, 41.5, 55.8, and 45.5 percent of surveyed alpine wet meadow, alpine meadow, and alpine steppe inhabitants, respectively, felt that the problem of decline in area of grasslands or pastures was "very serious" (Table 5.70).

5.6.3 Survey Question 17: In your opinion, when did the problem of decline in area of grasslands or pastures begin to occur?

Table 5.71 Period of occurrence of the onset of decline in area of grasslands or pastures, all survey respondents

Onset of Decline in Area of Grasslands or Pastures	Number of Survey Respondents	Percentage of Survey Respondents
Before 1950	1	0.5
1950-1969	1	0.5
1970-1979	0	0.0
1980-1989	73	36.5
1990-1999	59	29.5
2000-2005	60	30.0
Hasn't Occurred	6	3.0
Total	200	100 %

Table 5.72 Period of occurrence of the onset of decline in area of grasslands or pastures, by county

County	Zhidoi County		Chumarleb County	
Onset of Decline in Area of Grasslands or Pastures	**Number of Surveyed Zhidoi County Residents**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Surveyed Chumarleb County Residents**	**Percentage of Surveyed Chumarleb County Residents**
Before 1950	1	1.1	0	0.0
1950-1969	0	0.0	1	0.9
1970-1979	0	0.0	0	0.0
1980-1989	39	41.5	34	32.1
1990-1999	21	22.3	38	35.9
2000-2005	29	30.9	31	29.3
Hasn't Occurred	4	4.3	2	1.9
Total	94	100 %	106	100 %

Table 5.73 Period of occurrence of the onset of decline in area of grasslands or pastures, by occupation

Occupation	**Herders**		**Non-Herders**	
Onset of Decline in Area of Grasslands or Pastures	**Number of Surveyed Herders**	**Percentage of Surveyed Herders**	**Number of Surveyed Non-Herders**	**Percentage of Surveyed Non-Herders**
Before 1950	1	0.8	0	0.0
1950-1969	1	0.8	0	0.0
1970-1979	0	0.0	0	0.0
1980-1989	48	36.1	25	37.3
1990-1999	33	24.8	26	38.8
2000-2005	44	33.1	16	23.9
Hasn't Occurred	6	4.5	0	0.0
Total	133	100 %	67	100 %

Table 5.74 Period of occurrence of the onset of decline in area of grasslands or pastures, by type of grassland inhabited

Grassland Type	**Alpine Wet Meadow**		**Alpine Meadow**		**Alpine Steppe**	
Onset of Decline in Area of Grasslands or Pastures	**Number of Surveyed Wet Meadow Residents**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Surveyed Alpine Meadow Residents**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Surveyed Alpine Steppe Residents**	**Percentage of Surveyed Alpine Steppe Residents**
Before 1950	0	0.0	0	0.0	1	1.5
1950-1969	0	0.0	0	0.0	1	1.5
1970-1979	0	0.0	0	0.0	0	0.0
1980-1989	17	32.1	19	36.5	26	39.4
1990-1999	13	24.5	16	30.8	17	25.8
2000-2005	21	39.6	15	28.9	19	28.8
Hasn't Occurred	2	3.8	2	3.9	2	3.0
Total	53	100 %	52	100 %	66	100 %

Note: Town dwellers were not included in the analysis by type of grassland inhabited.

Survey respondents' views concerning the onset of declines in the area of grasslands and pastures suitable for grazing livestock closely parallel their views concerning the onset of grassland degradation or desertification (Survey Question 13), with the largest share of survey respondents, 36.5 percent, stating that the area of grasslands and pastures suitable for grazing began to decline during the 1980s (Table 5.71). Notably, the phenomena of degradation and decline in area of grasslands and pastures predates to a certain extent respondents' perceptions of the onset of obvious changes in the climate (Table 5.13). However, in total, 96 percent of survey respondents placed the onset of the decline in area of grasslands and

pastures as occurring between 1980 and 2005 (Table 5.71). The largest share of surveyed residents of Zhidoi County, 41.5 percent, stated that the decline in area of grasslands and pastures began during the 1980s, while the largest share of residents of Chumarleb County, 35.9 percent, placed the onset of this problem during the 1990s (Table 5.72). Amongst herders, the largest share of those surveyed, 36.1 percent, placed the onset of the decline in area of grasslands and pastures as occurring during the 1980s, while the largest share of non-herders, 38.8 percent, placed the onset of this problem as occurring during the 1990s (Table 5.73). In terms of the type of grassland inhabited, the largest share of surveyed inhabitants of alpine meadows and alpine steppe, 36.5 and 39.4 percent, respectively, placed the onset of the decline in area of grasslands and pastures suitable for grazing as occurring during the 1980s, while the largest share of inhabitants of alpine wet meadows, 39.6 percent, placed the onset of this problem as occurring between 2000 and 2005 (Table 5.74).

5.6.4 Survey Question 18: In your opinion, what are the main causes of the decline in area of grasslands or pastures?

Table 5.75 Causes of the decline in area of grasslands or pastures, all survey respondents

Causes of Grassland and Pasture Area Decline	Number of Responses	Percentage of All Responses	Percentage of Survey Respondents
Climate Change	126	25.9	63.0
Appearance of Rodent Infestations on Grasslands	98	20.2	49.0
Decreasing Availability of Water Resources	56	11.5	28.0
Opening of too Many Mines	51	10.5	25.5
Degradation of Grass Species	33	6.8	16.5
Natural Decreases in Area of Grasslands	22	4.5	11.0
Appearance of Plant Diseases and Insect Pests	19	3.9	9.5
Division of Pastures amongst Households	12	2.5	6.0
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	11	2.3	5.5
Inappropriate Herding Methods	10	2.1	5.0
Human Population Increase	9	1.9	4.5
Livestock Numbers too High	8	1.7	4.0
Inappropriate Government Policies	7	1.4	3.5
4 and 7 Complete Sets Government Programs	4	0.8	2.0
Other	20	4.1	10.0
Total	486	100 %	N/A

Note: Survey respondents were permitted to cite up to three causes. Percentages are based on 200 survey respondents.

Table 5.76 Causes of the decline in area of grasslands or pastures, by county

County	**Zhidoi County**		**Chumarleb County**	
Causes of Grassland and Pasture Area Decline	**Number of Responses**	**Percentage of Surveyed Zhidoi County Residents**	**Number of Responses**	**Percentage of Surveyed Chumarleb County Residents**
Climate Change	60	63.8	66	62.3
Appearance of Rodent Infestations on Grasslands	36	38.3	62	58.5
Decreasing Availability of Water Resources	24	25.5	32	30.2
Opening of too Many Mines	31	33.0	20	18.9
Degradation of Grass Species	15	16.0	18	17.0
Natural Decreases in Area of Grasslands	7	7.4	15	14.2
Appearance of Plant Diseases and Insect Pests	10	10.6	9	8.5
Division of Pastures amongst Households	9	9.6	3	2.8
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	6	6.4	5	4.7
Inappropriate Herding Methods	2	2.1	8	7.5
Human Population Increase	5	5.3	4	3.8
Livestock Numbers too High	3	3.2	5	4.7
Inappropriate Government Policies	6	6.4	1	0.9
4 and 7 Complete Sets Government Programs	4	4.3	0	0
Other	8	8.5	12	11.3
Total	226	N/A	260	N/A

Note: Survey respondents were permitted to cite up to three causes. Percentages are based on 94 and 106 survey respondents from Zhidoi and Chumarleb, respectively.

Table 5.77 Causes of the decline in area of grasslands or pastures, by occupation

Occupation	**Herders**		**Non-Herders**	
Causes of Grassland and Pasture Area Decline	**Number of Responses**	**Percentage of Surveyed Herders**	**Number of Responses**	**Percentage of Surveyed Non-Herders**
Climate Change	94	70.7	32	47.8
Appearance of Rodent Infestations on Grasslands	60	45.1	38	56.7
Decreasing Availability of Water Resources	39	29.3	17	25.4
Opening of too Many Mines	27	20.3	24	35.8
Degradation of Grass Species	20	15.0	13	19.4
Natural Decreases in Area of Grasslands	13	9.8	9	13.4
Appearance of Plant Diseases and Insect Pests	10	7.5	9	13.4
Division of Pastures amongst Households	7	5.3	5	7.5
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	3	2.3	8	11.9
Inappropriate Herding Methods	5	3.8	5	7.5
Human Population Increase	3	2.3	6	9.0
Livestock Numbers too High	3	2.3	5	7.5
Inappropriate Government Policies	3	2.3	4	6.0
4 and 7 Complete Sets Government Programs	2	1.5	2	3.0
Other	19	14.3	1	1.5
Total	308	N/A	178	N/A

Note: Survey respondents were permitted to cite up to three causes. Percentages are based on 133 and 67 herder and non-herder survey respondents, respectively.

Table 5.78 Causes of the decline in area of grasslands or pastures, by type of grassland inhabited

Grassland Type	Alpine Wet Meadow		Alpine Meadow		Alpine Steppe	
Causes of Grassland and Pasture Area Decline	**Number of Responses**	**Percentage of Surveyed Wet Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Meadow Residents**	**Number of Responses**	**Percentage of Surveyed Alpine Steppe Residents**
Climate Change	33	62.3	32	61.5	53	80.3
Appearance of Rodent Infestations on Grasslands	18	34.0	28	53.8	35	53.0
Decreasing Availability of Water Resources	11	20.8	15	28.8	24	36.4
Opening of too Many Mines	12	22.6	11	21.2	17	25.8
Degradation of Grass Species	12	22.6	6	11.5	8	12.1
Natural Decreases in Area of Grasslands	9	17.0	5	9.6	3	4.5
Appearance of Plant Diseases and Insect Pests	1	1.9	7	13.5	3	4.5
Division of Pastures amongst Households	3	5.7	3	5.8	3	4.5
Too Much Digging of Caterpillar Fungus (*Cordyceps sinensis*)	2	3.8	2	3.8	4	6.1
Inappropriate Herding Methods	1	1.9	3	5.8	1	1.5
Human Population Increase	0	0	2	3.8	5	7.6
Livestock Numbers too High	0	0	2	3.8	3	4.5
Inappropriate Government Policies	2	3.8	4	7.7	1	1.5
4 and 7 Complete Sets Government Programs	2	3.8	1	1.9	0	0
Other	12	22.6	5	9.6	3	4.5
Total	118	N/A	126	N/A	163	N/A

Note: Town dwellers were not included in the analysis by type of grassland inhabited. Survey respondents were permitted to cite up to three causes. Percentages are based on 53, 52, and 66 surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively.

As with the causes of grassland degradation or desertification (Survey Question 14), the top four causes cited by survey respondents for the decline in area of grasslands and pastures suitable for grazing livestock were climate change (cited by 63 percent of all survey respondents), rodent infestations (49 percent of respondents), decline in water availability (28 percent of respondents), and too many mines (25.5 percent of respondents) (Table 5.75). Similar numbers of survey respondents in Zhidoi and Chumarleb Counties, 63.8 and 62.3 percent, respectively, cited climate change as a primary cause of the decline in area of grasslands and pastures (Table 5.76). However, 58.5 percent of respondents from Chumarleb County cited rodent infestations as a cause of the decline in area of grasslands or pastures versus just 38.3 percent of respondents from Zhidoi County. But while 33 percent of those surveyed in Zhidoi cited mining as a cause of this problem, only 18.9 percent of respondents from Chumarleb County cited this cause (Table 5.76). In terms of occupation, a much higher proportion of herders (70.7 percent) than non-herders (47.8 percent) surveyed cited climate change as a primary cause of decline in the area of grasslands and pastures (Table 5.77). In terms of type of grassland occupied, 62.3, 61.5, and 80.3 percent of surveyed inhabitants of alpine wet meadows, alpine meadows, and alpine steppe, respectively, cited climate change as a primary cause of the decline in area of grasslands and pastures (Table 5.78). The second most commonly cited cause of this problem amongst surveyed grassland inhabitants was rodent infestations, which were cited by 34, 53.8, and 53 percent of inhabitants of alpine wet meadows, alpine meadow, and alpine steppe, respectively, (Table 5.78). Again, as with grassland degradation and desertification, only a small percentage of survey respondents, 4 percent, cited livestock numbers being too high as a cause of the decline in area of grasslands and pastures suitable for grazing, although in fact, overgrazing resulting from overstocking of pastures with livestock is perhaps the leading cause of this problem (Table 5.75).

5.7 Discussion

Of the surveyed residents of the Yangtze Source Region, an overwhelming 84.5 percent stated that there had been either “fairly obvious” or “very obvious” changes to the local climate, with 94.5 percent of respondents stating that these changes had occurred at various times between 1980 and 2005 (Table 5.9, Table 5.13). Notably, 56.4 percent of herders versus 38.8 percent of non-herders stated that there had been “very obvious” changes in the local climate, which suggests that herders spending long hours out on the grasslands every day are more sensitive to climate change than non-herders (Table 5.11). In terms of how climate change has manifested itself in the Yangtze Source Region, in general, the majority of survey respondents, 67 percent, felt that summers are now cooler than in former times, with summer now being generally shorter and there being more summer snowfalls and high wind events than in times past (Table 5.18, Table 5.22). Notably, however, 84.2 percent of herders surveyed felt summers are now cooler, while in sharp contrast, 58.2 percent of surveyed non-herders felt summers are now hotter (Table

5.20). With respect to winter, 50 percent of survey respondents stated that winters are now warmer in the Yangtze Source Region than in the past (Table 5.26). However, as with summer temperatures, views on this matter were split along occupational lines, with only 42.1 percent of herders feeling winters are now warmer versus 64.2 percent of non-herders who felt so (Table 5.28). Changes in winter weather phenomena cited by survey respondents included more high wind events, less snowfall, and winters being generally longer than in former times (Table 5.30). For climatic changes in both summer and winter, there was significant variation in responses based on location, with, for example, 68.1 percent of surveyed residents of Zhidoi County citing less snowfall in winter versus just 22.6 percent of surveyed residents of Chumarleb County who cited this phenomena, while 74.5 percent of survey respondents in Chumarleb County cited an increase in winter high wind events versus just 42.6 percent of respondents in Zhidoi County who noted this phenomena (Table 5.31).

When asked what were the harmful impacts of climate change on the local environment and ecology, the leading responses were a decline in grass quality (55 percent of all survey respondents), increased rodent infestations (46 percent of all respondents) and desertification (36 percent of all respondents) (Table 5.38). Notably, in Zhidoi County, a close fourth response was insufficient rainfall, which was cited by 29.8 percent of surveyed residents of that county (Table 5.39). Furthermore, 92.5 percent of all survey respondents stated that there was either a "fairly close" or "very close" relationship between climate change and grassland degradation and desertification (Table 5.47), with 86.5 percent of all respondents stating that the problems of grassland degradation and desertification in the region are either "fairly serious" or "very serious" (Table 5.51). Residents of both Chumarleb County and inhabitants of alpine steppe grasslands felt the problems of grassland degradation and desertification are particularly acute, with 69.8 percent and 60.6 percent of these survey respondents, respectively, stating that these problems are "very serious" (Table 5.52, Table 5.54). Correspondingly, 89.5 percent of all survey respondents stated that there was either a "fairly close" or "very close" relationship between climate change and the decline in the area of pastures and grasslands suitable for grazing livestock (Table 5.63), while 82 percent of all respondents stated that the problem of the decline in area of pastures and grasslands suitable for grazing livestock was either "fairly serious" or "very serious" (Table 5.67). In total, 63 percent of all survey respondents cited climate change as a cause of decline in area of pastures and grasslands suitable for grazing livestock, while the second most frequently cited cause of this problem was an increasing occurrence of rodent infestations, as stated by 49 percent of all survey respondents (Table 5.75).

When asked about the positive effects of climate change on the local livestock industry, the majority of survey respondents, 57 percent, simply stated that there were no positive effects (Table 5.42). The remaining respondents were widely divided on what effects of climate change they felt were beneficial for livestock,

with the most noted positive effects being improved forage quality, cited by a small minority of 17.5 percent of survey respondents, and improved grass and water availability, cited by just 14 percent of respondents (Table 5.42). However, when asked about the harmful effects of climate change on the local livestock industry, there was no shortage of thoughts on the matter, with the leading responses being a decline in forage quality, cited by 43 percent of all survey respondents, an increase in insect and rodent infestations, cited by 40.5 percent of respondents, and an increase in livestock disease, cited by 29.5 percent of survey respondents (Table 5.43). It should be kept in mind, however, that while changing patterns of temperature and precipitation and the degradation of vast areas of permafrost in the Yangtze Source Region as a result of climate change will lead to dramatic changes in grassland ecosystems, overgrazing is also a cause of pasture degradation and proliferation of non-palatable invasive grassland species. And as discussed in Chapter 2 of this report, some scientists feel that the proliferation of rodent infestations in the region may be a result of widespread pasture damage caused by overgrazing, not a cause of pasture degradation resulting from climate change as suggested by the responses to this survey. The third most cited harmful effect of climate change on the local livestock industry was an increase in livestock disease, cited by 29.5 percent of respondents, although the connection between climate change and livestock disease in the Yangtze Source Region is not entirely clear and was not discussed in the survey (Table 5.43).

Based on the anecdotal comments of survey respondents, warm season in the Yangtze Source Region used to last from about mid-May to early November, however, residents are presently reporting that warm season is now nearly two months shorter, lasting from just mid-June to mid-October. It is important to note that climate change directly impacts the livelihoods of local herders, most of whom are entirely dependent on their livestock for their food supply and the extra cash or barter income needed to obtain other daily necessities. Thus, it is not surprising that this survey found local herders to be particularly aware of climatic changes occurring during warm season (e.g. see Table 5.20), as conditions during this period determine the quantity of the annual grass supply for the region's livestock as well as being the season most critical for the survival of newborn calves and lambs and for the production of milk and milk products, such as cheese, to be stored for consumption throughout the long cold season. Consequently, a shortening of the warm season by nearly two months can be expected to have a significant negative impact on annual grass production, and hence milk production, and also on the survival rate of the season's newborn calves and lambs. Nevertheless, although increasing human populations, exceedingly high numbers of livestock, and pasture privatization, which decreases livestock mobility by restricting household herds to small family-held pastures, were only cited as causes of grassland degradation or desertification by 3.5, 3.5, and 6 percent of survey respondents respectively, research has shown that these three factors may be leading causes of widespread overgrazing in the region that can result in large-scale desertification (Table 5.59). However, it should come as no surprise that the vast majority of herders, 74.4 percent, cited climate change as the primary cause of grassland degradation or

desertification rather than high numbers of livestock grazing on the region's fragile grasslands, as these livestock herds are their primary source of income and the largest form of employment in the Yangtze Source Region (Table 5.61).

5.8 Conclusions

When presented with the opportunity to do so, surveyed livestock herders in the Yangtze Source Region overwhelmingly placed the blame for the widespread problems of declining pasture quality, desertification, and the subsequent decline in livestock productivity on a changing climate. In fact, the climate of the region is changing, with herders frequently citing summer, the peak growing season for the region's grasslands, as being both cooler and shorter, and subject to an increasing frequency of summer snowfall events — all of which are detrimental to the growth of grass and the survival of newborn calves and lambs. However, it must be kept in mind that grassland degradation on the Qinghai-Tibet Plateau is a multi-faceted process. As discussed in Chapter 2 of this report, sand dunes began appearing on the grasslands of the northeastern Qinghai-Tibet Plateau in the 1960s, about the same time that large-scale herding cooperatives were established in the region and long before the generally agreed upon initial onset of "obvious" changes in the climate in the 1980s that was cited by survey respondents. However, while the problem of grassland degradation on the Qinghai-Tibet Plateau is due in large part to the rapid increase in domestic livestock numbers in the region over the past five decades, from the findings of this survey it should be clear that this problem is being greatly exacerbated by regional climate change, and that reduced grassland productivity resulting from climate change is no doubt adversely affecting the livelihoods of herders in the Yangtze Source Region. Consequently, any future plans for development of the Yangtze Source Region will need to include an effective climate change adaptation strategy for the local livestock herding industry if the standard of living of the region's herders, who comprise the majority of the local population, is to improve.

Afterword

From the preceding reports it should be obvious that the impacts of climate change on the Qinghai-Tibet Plateau are extremely complex, and that there is as yet no clear picture of how climate change will affect the plateau region in the future. However, what is clear is that temperatures on the Qinghai-Tibet Plateau have been steadily rising at unprecedented rates since the 1970s, with most scientists attributing these rapid increases in temperature to the anthropogenic emission of greenhouse gases. In the recent scientific literature on the topic there is much discussion about a general climatic “warming and drying trend” on the Qinghai-Tibet Plateau over the past century, which has been evidenced by the drying up of numerous rivers, lakes, and wetlands in the region, perhaps most notably by the receding shoreline of Qinghai Lake. Yet there is now a growing amount of evidence to indicate that precipitation in many parts of the Qinghai-Tibet Plateau has actually begun to increase in the past decade. This evidence includes both scientific measurements and the anecdotal reports of residents of the plateau, particularly those of local nomadic livestock herders who spend all of their days out on the land and are acutely aware of changes in local weather patterns.

While the levels of many lakes on the plateau were already rising due to the rapid meltoff of the plateau’s glaciers that began in the early 1990s, this meltoff is now being supplemented in some areas by recent increases in precipitation, which at Qinghai Lake alone has led to a 50 cm rise in lake surface level between 2004 and 2008. Paradoxically, however, this increase in precipitation may not be sufficient to counteract the rapid loss of the plateau’s glacier resources to climatic warming or offset the widespread loss of high altitude wetlands due to the degradation of the permafrost that underlies these wetlands, which ordinarily prevents the deep percolation of surface waters. In some cases, these increases in precipitation and lake levels are actually inundating grasslands, significantly reducing the amount of pasturelands available to the affected communities. In addition, although climate change has led to a significant increase in winter temperatures, many residents of the plateau, in particular the herders who are the majority of the population of the northern plateau, have stated that summer temperatures are now actually cooler than in previous decades, and many have even reported that snowfall in summer is increasing.

While at first glance cooling summer temperatures might appear to be good news with respect to climate change, this situation may prove to have a severe impact on the plateau’s livestock herding economy. At present, plateau herders are already suffering from the loss of grasslands due to the drying up of wetlands and lowering of groundwater levels resulting from permafrost degradation as well as due to widespread pasture degradation and desertification resulting from overgrazing, problems which are further compounded by climate change. If summers on the plateau are in fact growing cooler and shorter, it is anticipated that grassland

productivity and the survival rate of newborn livestock will both decline, situations that will have dire consequences for growing herding communities already suffering from declines in livestock productivity. A far more uncertain question is that of how climatic warming on the plateau will ultimately affect the plateau's abundant wildlife, such as the wild yak, an issue which is critical to the continued survival of the plateau's wild animal species since all are adapted to living in one of the world's coldest climates.

Regardless of the ultimate course climate change takes on the Qinghai-Tibet Plateau, be it either towards a warm-dry or a warm-wet climate as is generally anticipated by scientific researchers, the implications of climatic warming for the plateau's herders, ecosystems, wildlife, and the general economic development of the region are enormous. Thus, there is an urgent need to halt all further preventable damage to the plateau's ecosystems caused directly by human activities, such as overgrazing of livestock and other poor land-use practices, and to develop effective climate adaptation strategies for both future warm-dry and warm-wet climate scenarios on the Qinghai-Tibet Plateau. An important feature of any future climate adaptation strategy for the plateau should naturally be the development of alternative livelihoods for the continually growing populations of Tibetan herders and farmers who, at present, are directly dependent on the plateau's declining natural resource base for their survival.

Furthermore, hundreds of millions of downstream users in China, South Asia, and Southeast Asia rely on water resources originating on the Qinghai-Tibet Plateau for their day-to-day existence. Therefore, the impact of climate change on the plateau's glaciers, permafrost, rivers, lakes, and wetlands is also an issue of tremendous international importance that will require the cooperation of the international community to resolve.

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Appendix A: Glossary of Technical Terms

(Compiled from various online sources.)

Ablation
The loss of ice and snow from a glacier system. This occurs through a variety of processes including melting and runoff, sublimation, evaporation, calving, and wind transportation of snow out of a glacier basin.

Accumulation
The addition of ice and snow into a glacier system. This occurs through a variety of processes including precipitation, firnification, and wind transportation of snow into a glacier basin from an adjacent area.

Accumulation Area
The part of a glacier that is perennially covered with snow.

Accumulation Area Ratio
The accumulation area ratio of a glacier, AAR, is the percentage of a glacier that is a snow-covered accumulation zone at the end of the summer melt season.

Active Layer
In areas underlain by permafrost, the active layer is the uppermost layer of ground that is subject to annual thawing and freezing.

Active-layer Thickness
The thickness of the layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost.

Advance
An increase in the length of a glacier compared to a previous point in time. As ice in a glacier is always moving forward, a glacier's terminus advances when less ice is lost due to melting and/or calving than the amount of yearly advance.

Altitudinal Limit of Permafrost
The lowest altitude at which mountain permafrost occurs in a given highland area outside the general northern and southern permafrost regions.

Bacillariophyta
A phylum of algae comprising the diatoms. These marine or freshwater unicellular organisms have cell walls (frustules) composed of pectin impregnated with silica and consist of two halves, one overlapping the other.

Benthic Fauna
Organisms attached to or resting on the bottom or living in the bottom sediments of a water body.

Biogeochemical Cycles
A biogeochemical cycle or nutrient cycle is a pathway by which a chemical element or molecule moves through both biotic (biosphere) and abiotic (lithosphere, atmosphere, and hydrosphere) realms of Earth.

Cenozoic
The most recent of the three classic geological eras that covers the period from 65.5 million years ago to the present.

Chlorophyta
A division of green algae that includes about 7000 species of mostly aquatic photosynthetic eukaryotic organisms. Like the land plants (bryophytes and tracheophytes), green algae contain chlorophylls a and b, and store food as starch in their plastids.

Climate Change
Climate change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average, for example, greater or fewer extreme weather events. Climate change may be limited to a specific region, or may occur worldwide.

Continuous Permafrost
Permafrost occurring everywhere beneath the exposed land surface throughout a geographic region with the exception of widely scattered sites, such as newly deposited unconsolidated sediments, where the climate has just begun to impose its influence on the thermal regime of the ground, causing the development of continuous permafrost.

Cyanophyta
Cyanophyta, also known as blue-green algae, blue-green bacteria, or cyanobacteria is a phylum of bacteria that obtain their energy through photosynthesis.

Desertification
The transformation of land once suitable for agriculture into desert. Desertification can result from climate change or from human practices such as deforestation and overgrazing.

Diatoms
Any of various microscopic one-celled or colonial algae of the class Bacillariophyceae, having cell walls of silica consisting of two interlocking symmetrical valves.

Discontinuous Permafrost
Permafrost occurring in some areas beneath the exposed land surface throughout a geographic region where other areas are free of permafrost.

Equilibrium Line
The equilibrium line of a glacier is the location where winter accumulation of snow is equal to summer ablation.

GIS (Geographic Information Systems)
A geographic information system (GIS) captures, stores, analyzes, manages, and presents data that is linked to location. Technically, GIS includes mapping software and its application with remote sensing, land surveying, aerial photography, mathematics, photogrammetry, geography, and tools that can be implemented with GIS software.

Global Climatic Abnormality
Abnormalities in climate affecting vast regions of the earth simultaneously, such as extended periods of drought or intense precipitation, perhaps the best known of which is the recurring El Niño phenomenon.

Gramineous
Of, relating to, or characteristic of grasses or belonging to the grass family.

Groundwater Table
Surface of a body of underground water below which the soil or rocks are permanently saturated with water. The water table separates the groundwater zone (zone of saturation) that lies below it from the zone of aeration that lies above it. The groundwater table fluctuates both with the seasons and from year to year because it is affected by climatic variations and by the amount of precipitation. It also is affected by withdrawing excessive amounts of water from wells.

Holocene
A geological epoch which began approximately 12,000 years ago and extends to the present.

Holocene Climatic Optimum
A period of warm climatic conditions that occurred roughly between 9000 to 5000 ybp.

Holocene Neoglaciation
A period of cool climatic conditions that occurred roughly between 4500 and 2500 ybp.

Humic Acid
Any of a number of various complex organic acids obtained from humus that are insoluble in acids.

Ice Cap
An ice mass that covers less than 50,000 km² of land area, usually in a highland area. Ice caps are not constrained by topographical features and will lie over the top of mountains, but their dome is usually centered on the highest point of a massif.

Initial Rainfall
Rainfall at the beginning of a storm that is considered to end when depression storage on the land surface is completely filled and runoff begins.

Little Ice Age
A period of cool climatic conditions that occurred roughly between 1500 and 1850 A.D.

Macrophytes
A member of the macroscopic plant life, especially of a body of water.

Mass Balance
A measure of the change in mass of a glacier at a certain point for a specific period of time, specifically the balance between accumulation and ablation from a glacier's surface.

Medieval Warm Period
A period of warm climatic conditions in the Northern hemisphere that occurred roughly between 900 and 1300 AD.

Neogene
The latter half of the Tertiary geologic period which began about 23.03 million years ago and ended 2.588 million years ago with the beginning of the Quaternary.

Ostracods
Any of various minute, chiefly freshwater crustaceans of the subclass Ostracoda, having a bivalve carapace.

Paleogene
The first half of the Tertiary geologic period which began about 65.5 million years ago and ended about 23.03 million years ago, which also comprises the first part of the Cenozoic era.

Pasture Degradation
Pasture degradation is a process that occurs as a result of poor land management practices, usually overstocking of livestock, and results in soil compaction, reduced fertility of soils, lower forage productivity, proliferation of undesirable or unpalatable invasive plant species, and, in extreme cases, desertification.

Peat
Partially carbonized vegetable tissue formed by partial decomposition in water of various plants, e.g. mosses of the genus Sphagnum.

Perched Aquifers
A perched aquifer (or perched water table) is an aquifer that occurs above the regional water table, in the vadose zone. This occurs when there is an impermeable layer of rock or sediment (aquiclude) or relatively impermeable layer (aquitard) above the main aquifer but below the surface of the land that blocks the infiltration of groundwater to the main aquifer.

Permafrost
Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.

Permafrost Degradation
A naturally or artificially caused decrease in the thickness and/or areal extent of permafrost.

Phytoplankton
Minute, free-floating aquatic plants such as algae.

Piedmont
An area of land formed or lying at the foot of a mountain or mountain range.

Pleistocene
A geological epoch that occurred roughly between 2.6 million and 12,000 ybp, and included the world's most recent period of repeated glaciations or ice ages.

Principle of Maximum Entropy
The Principle of Maximum Entropy is a technique that can be used to estimate input probabilities more generally. The result is a probability distribution that is consistent with known constraints expressed in terms of averages, or expected values, of one or more quantities, but is otherwise as unbiased as possible.

Quaternary
A geological period which began approximately 2.6 million years ago and extends to the present.

Remote Sensing
The acquisition and measurement of data/information on some property of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature under surveillance, such as through the use of satellite imagery or aerial photography.

Ruderal Plants
Plant species that are associated with human dwellings or agriculture, or ones that colonize waste ground. Ruderals are often weeds that occupy disturbed ground, such as land along roadsides, which have high demands for nutrients and/or are intolerant of competition

Retreat
A decrease in the length of a glacier compared to a previous point in time. As ice in a glacier is always moving forward, its terminus retreats when more ice is lost at the terminus to melting and/or calving than reaches the terminus. During retreat, ice in a glacier does not move back up its valley.

Runoff Coefficient
An index used to estimate the proportion of precipitation that will appear as runoff that varies with the type of surface the precipitation is falling on. Runoff co-efficients are usually obtained from a predetermined list of values for a variety of surfaces under different conditions, with average coefficients for large watersheds with a variety of surface types being estimated using various area-weighted methods.

Sedge
Any species of the Cyperaceae family or sedge family of usually tufted mono-cotyledonous marsh plants differing from the related grasses in having achenes and solid stems.

Soil Salinization
In a soil of an arid, poorly drained region, the accumulation of soluble salts by the evaporation of the waters that bore them to the soil zone.

Temperature Anomaly
The deviation of a given temperature value in a series, e.g. the annual mean temperature for a given year, from the overall mean temperature for that series, e.g. the overall annual mean temperature for a given 20-year series of annual mean temperatures.

Water Balance Principle
The water balance principle states the volume of surface runoff, Q, is equal to the volume of precipitation, P, minus the volumes of water lost to evaporation, E, drainage to groundwater, D, and change in soil water content, ΔS. $Q = P - E - D - \Delta S$

Xerophilic
Thriving in or tolerant or characteristic of a xeric, or low-moisture, environment.

Zooplankton
Tiny, free-floating organisms in aquatic systems that include animals suspended in water with limited powers of locomotion. Freshwater zooplankton are dominated by four major groups of animals: protozoa, rotifers, and two subclasses of the Crustacea, the cladocerans and copepods.

Appendix B
Locations of All Place Names Mentioned in the Text

(Note: Latitude and longitude coordinates are approximate only.)

Also See:
Table 3.3: List and Locations of River Gage Stations in the Yangtze Source Region
Table 4.2: List and Locations of Permafrost Observation Sites near the Qinghai-Tibet Highway
Appendix C: List and Locations of Meteorological Stations on the Qinghai-Tibet Plateau
Appendix D: Lakes of the Yangtze Source Region with Surface Areas ≥0.5 km^2

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
66 Daoban Permafrost Observation Site	66 道班多年冻土观测场 66 Daoban Duonian Dongtu Guance Chang	Qinghai	35º31' N, 93º48' E
Acai Village	阿莱村 Acai Cun	Qinghai	Chumar River Township, Chumarleb County
Amdo County	安多县 Anduo Xian	TAR	32°15' N, 91°42' E
Amdo South Mountain	安多南山 Anduo Nan Shan	TAR	32°13' N, 91°42' E
Angla Village	昂拉村 Angla Cun	Qinghai	Chumar River Township, Chumarleb County
Bai He River	白河 Bai He	Sichuan	33°10' N, 102°30' E
Bajiu Co Lake	巴纠错 Bajiu Cuo	TAR	28°45' N, 90°50' E
Baladacai Chu	巴拉大才曲 Baladacai Qu	Qinghai	35°28' N, 93°47' E
Balongchin Chu River <u>or</u> Bolong Chu River	波陇曲<u>or</u> 巴陇钦曲 Bolong Qu <u>or</u> Balongqin Qu	Qinghai	Tributary of the Tuotuo River
Bangdag Co Lake	邦达错 Bangda Cuo	TAR	34°55' N, 81°30' E
Bangkog Lake	班戈错 Bange Cuo	TAR	31°43' N, 89°29' E
Bangong Co Lake	班公错 Bangong Cuo	TAR	33°30' N, 79°48' E
Bayan Har Mountain	巴颜喀拉山 Bayan Kala Shan	Qinghai, Sichuan	34°10' N, 97°15' E
Beilu River <u>or</u> Leima Chu River	北麓河 <u>or</u> 勒玛曲 Beilu He <u>or</u> Leima Qu	Qinghai	34°40' N, 93°30' E
Bencao Chu River	奔草曲 Bencao Qu	Qinghai	Tributary of the Dam Chu River
Bianenghou River	笔阿能后曲 Bi'a'nenghou Qu	Qinghai	Tributary of the Dam Chu river
Bi Chu River	布曲 Bu Qu	Qinghai	33°32' N, 92°00' E
Bi Chu River Source	布曲源 Bu Qu Yuan	Qinghai	32°51' N, 91°58' E
Brahmaputra (Yarlung Tsangpo River)	雅鲁藏布江 Yalu Zangbu Jiang	TAR	29°22' N, 90°00' E
Chabyer Caka Lake	扎布耶茶卡 Zhabuye Chaka	TAR	31°22' N, 84°03' E

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Chadang Chu River	杈当曲 Chadang Qu	Qinghai	Tributary of the Dam Chu River
Chagcam Caka Lake	扎仓茶卡 Zhacangchaka	TAR	32°34’ N, 82°23’ E
Chamdo Prefecture	昌都地区 Changdu Diqu	TAR	31°10’ N, 97°14’ E
Chang Tang Region	羌塘 Qiangtang	TAR, Qinghai	Roughly bounded by 30°-36° N, 79°-96° E
Chaqin Chu River	查钦曲 Chaqin Qu	Qinghai	Tributary of the Bi Chu River
Chawu Chu River	查吾曲 or 杈五曲 Chawu Qu	Qinghai	Tributary of the Dam Chu River
Chen Co Lake	沉错 Chen Cuo	TAR	28°56’ N, 90°30’ E
Chindu County	称多县 Chengduo Xian	Qinghai	33°25’ N, 97°07’ E
Chongtian River	冲天河 Chongtian He	Sichuan	28°19’ N, 100°38’ E
Chumar River	楚玛尔河 Chumaer He	Qinghai	35°18’ N, 93°00’ E
Chumar River Gage Station	楚玛尔河水文站 Chumaer He Shuiwen Zhan	Qinghai	35°18’ N, 93°17’ E
Chumar River Township	曲麻河乡 Quma He Xiang	Qinghai	34°51’ N, 94°57’ E
Chumarleb (Qumarleb) County	曲麻莱县 Qumalai Xian	Qinghai	34°08’ N, 95°48’ E
Chumarleb Town (County Seat)	约改镇 Yuegai Zhen	Qinghai	34°08’ N, 95°48’ E
Chumarleb Meteorological Station	曲麻莱气象观测站 Qumalai Qixiang Guance Zhan	Qinghai	34°08’ N, 95°47’ E
Chumda River Gage Station (Tongtian River, Marks downstream end of the YSR)	直门达水文站 Zhimenda Shuiwen Zhan	Qinghai	33º01’ N, 97º14’ E
Co Lajian Lake	错拉坚 Cuo Lajian	Qinghai	33°52’ N, 102°50’ E
Co Ngoin Lake	错鄂 Cuo E	TAR	31°37’ N, 88°45’ E
Cuochi Village	措池村 Cuochi Cun	Qinghai	Chumar River Township, Chumarleb County
Dadu River	大渡河 Dadu He	Sichuan	30°00’ N, 102°12’ E
Daha Chu River	达哈曲 Daha Qu	Qinghai	Tributary of the Ranchi Chu River
Dam Chu River	当曲 Dang Qu	Qinghai	33°26’ N, 93°00’ E
Damshung County	当雄县 Dangxiong Xian	TAR	30°30’ N, 91°10’ E
Dangjiang Township	当江乡 Dangjiang Xiang	Qinghai	33º40’ N, 95º50’ E
Daotang He River	倒淌河 Daotang He	Qinghai	36º31’ N, 100º46’ E
Deliechuka River Gage Station (Garchu River)	得列楚卡 水文站 Deliechuka Shuiwen Zhan	Qinghai	33°50’ N, 92°22’ E
Denge Chu River	登额曲 Denge Qu	Qinghai	33°40’ N, 95°52’ E
Ding Chu	定曲 Ding Qu	Sichuan	29°00’ N, 99°25’ E
Dong Chu River	冬曲 or 旦曲 Dong Qu or Dan Qu	Qinghai	33°28’ N, 92°32’ E
Dongbuli Chu River	冬布里曲 Dongbuli Qu	Qinghai	Tributary of the Tongtian River
Dongbuli Range	冬布里山 Dongbuli Shan	Qinghai	34°32’ N, 93°16’ E
Dongkemadi Glacier (Small)	冬克玛底冰川 (小) Dongkemadi Bingchuan (Xiao)	Qinghai	33°04’ N, 92°04’ E

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Doqen Co Lake	多庆错 Duoqing Cuo	TAR	28°10’ N, 89°25’ E
Dulan County	都兰县 Dulan Xian	Qinghai	36°15’ N, 98°08’ E
Dun Chu River	敦曲 Dun Qu	Qinghai	Tributary of the Dam Chu River
Dunde Ice Cap	敦德冰盖 Dunde Binggai	Qinghai	38°06’ N, 96°25’ E
Duocai Township	多采乡 Duocai Xiang	Qinghai	33º45’ N, 95º25’ E
Duoren Chu River	多仁曲 Duoren Qu	Qinghai	Tributary of the Dam Chu River
Duoxiu Village	多秀村 Duoxiu Cun	Qinghai	Chumar River Township, Chumarleb County
Eamanacao Chu	鄂阿玛纳草曲 Eamanacao Qu	Qinghai	Tributary of the Dam Chu River
Eaxigongka Chu River	鄂阿西贡卡曲 Eaxigongka Qu	Qinghai	Tributary of the Dam Chu River
Elsen Nur Lake	叶鲁苏湖 <u>or</u> 错仁德加 Yelusu Hu <u>or</u> Cuo Rendejia	Qinghai	35º14’ N, 92º08’ E
Fenghuo Mountain	风火山 Fenghuo Shan	Qinghai	34°41’ N, 92°55’ E
Fujiang River	涪江 Fu Jiang	Sichuan	32°15’ N, 104°50’ E
Gaimalong	盖玛陇巴 Gaimalongba	Qinghai	Tributary of the Dong Chu River
Gangdise Range	冈底斯山 Gangdisi Shan	TAR	30°18’ N, 83°30’ E
Gangaisen Chu River	岗埃森曲 Gang’aisen Qu	Qinghai	Tributary of the Dam Chu River
Gangqin Peak (6137 m)	岗钦 Gangqin	Qinghai	33°53’ N, 90°42’ E
Gansu Province	甘肃省 Gansu Sheng	Gansu	35°00’ N, 104°00’ E
Ganzi County (Garze)	甘孜县 Ganzi Xian	Sichuan	31°37’ N, 99°58’ E
Gar Chu River	尕尔曲 Gaer Qu	Qinghai	33°48’ N, 92°00’ E
Garkyagdeugang <u>or</u> Gar Kangri Peak (6513 m)	嘎尔岗日 Gaer Gangri	Qinghai	33°30’ N, 90°55’ E
Geladandong Peak (6621 m)	各拉丹冬峰 Geladandong Feng	Qinghai	33°30’ N, 91°10’ E
Gerze County	改则县 Gaize Xian	TAR	32°18’ N, 84°03’ E
Golmud Municipality	格尔木市 Geermu Shi	Qinghai	36°25’ N, 94°52’ E
Golog Tibetan Autonomous Prefecture	果洛藏族自治州 Guoluo Zangzu Zizhi Zhou	Qinghai	34°00’ N, 100°00’ E
Gor Chu River	果曲 Guo Qu	Qinghai	Tributary of the Dam Chu River
Gounong Co Lake	苟弄错 Gounong Cuo	Qinghai	34°38’ N, 92°09’ E
Gouyang Village	郭洋村 Gouyang Cun	Qinghai	Maduo Township, Chumarleb County
Great Gorge of the Yarlung Tsangpo	雅鲁藏布江 大峡谷 Yalu Zangbu Jiang Da Xiagu	TAR	28°42’ N, 94°17’ E
Guliya Ice Cap	古里雅冰盖 Guliya Binggai	TAR, Xinjiang	35°17’ N, 81°29’ E
Gyaring Co Lake	扎陵湖 Zhaling Hu	Qinghai	34°52’ N, 97°15’ E
Gyelje Podrang (Zhidoi County Seat)	加吉博洛镇 Jiaji Boluo Zhen	Qinghai	33°50’ N, 95°37’ E

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Hainan Tibetan Autonomous Prefecture	海南藏族自治州 Hainan Zangzu Zizhi Zhou	Qinghai	36°00' N, 100°00' E
Haixi Mongolian and Tibetan Autonomous Prefecture	海西蒙古族藏族自治州 Haixi Mengguzu Zangzu Zizhi Zhou	Qinghai	37°00' N, 95°00' E
Haiyan Bay	海晏湾 Haiyan Wan	Qinghai	36°49' N, 100°43' E
Haiyan County	海晏县 Haiyan Xian	Qinghai	36°55' N, 100°58' E
Haqiu Lake	哈丘错 Haiqiu Cuo	Sichuan	33°48' N, 102°50' E
Hei He River	黑河 Hei He	Sichuan	33°45' N, 102°35' E
Heka South Mountain	河卡山南 Heka Shan Nan	Qinghai	35°48' N, 99°52' E
Henan County	河南蒙古族自治县 Henan Mengguzu Zizhi Xian	Qinghai	34°42' N, 101°40' E
Hengduan Mountains	横断山 Hengduan Shan	TAR, Yunnan, Sichuan	28°20' N, 98°25' E
Himalaya Range	喜马拉雅山 Ximalaya Shan	TAR, Nepal, India	28°00' N, 87°00' E
Hoh Xil Lake	可可西里湖 Keke Xili Hu	Qinghai	35°35' N, 91°00' E
Hoh Xil Permafrost Observation Site	可可西里多年冻土观测场 Keke Xili Duonian Dongtu Guance Chang	Qinghai	35º08' N, 93º03' E
Hoh Xil Range	可可西里山 Keke Xili Shan	Qinghai	35°20' N, 91°00' E
Huangnan Tibetan Autonomous Prefecture	黄南藏族自治州 Huangnan Zangzu Zizhi Zhou	Qinghai	35°00' N, 101°30' E
Indus (Senge Khabab)	森格臧布 Senge Zangbu	TAR	32°33' N, 80°28' E
Jianggendiru Glaciers	姜根迪如冰川 Jianggendiru Bingchuan	Qinghai	33°28' N, 91°07' E
Jialing River	嘉陵江 Jialing Jiang	Chongqing	30°00' N, 106°19' E
Jiangta Chu River	江塔曲 Jiangta Qu	Qinghai	Tributary of the Tuotuo River
Jigdril County	久治县 Jiuzhi Xian	Qinghai	33°27' N, 101°30' E
Jingxian Valley	惊仙谷 Jingxian Gu	Qinghai	35°46' N, 94°08' E
Jinsha River <u>or</u> Dri Chu (Upper Yangtze-Reach 3)	金沙江 Jinsha Jiang	TAR, Sichuan, Yunnan	32°00' N, 98°25' E
Jyekundo County	玉树县 Yushu Xian	Qinghai	33°02' N, 97°02' E
Jyekundo Town (County Seat)	结古镇 Jiegu Zhen	Qinghai	33°02' N, 97°02' E
Kangding County (Dartsedo)	康定县 Kangding Xian	Sichuan	30°03' N, 101°58' E
Karakorum Range	喀拉昆仑山 Kalakunlun Shan	Xinjiang	35°00' N, 77°30' E
Kugchen Chu River	口前曲 Kouqian Qu	Qinghai	34°20' N, 94°40' E
Kouqian Village	口前村 Kouqian Cun	Qinghai	Zhahe Township, Zhidoi County
Kunlun Pass	昆仑山口 Kunlun Shan Kou	Qinghai	35°38' N, 94°03' E
Kunlun Range	昆仑山 Kunlun Shan	Qinghai, TAR, Xinjiang	36°05' N, 90°00' E

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Kunlun Yakou Basin	昆仑山垭口盆地 Kunlun Shan Yakou Pendi	Qinghai	35°37’ N, 94º05’ E
Laiyong Village	来永村 Laiyong Cun	Qinghai	Yege Township, Chumarleb County
Laji Mountain	拉脊山 Laji Shan	Qinghai	36°21’ N, 101°26’ E
Lari Village	拉日村 Lari Cun	Qinghai	Duocai Township, Zhidoi County
Lariganmuzhangba Chu River	拉日干木章巴曲 Lariganmuzhangba Qu	Qinghai	Tributary of the Tuotuo River
Lechi Chu River	勒池曲 Leichi Qu	Qinghai	34°47’ N, 94°15’ E
Lechi Village	勒池村 Leichi Cun	Qinghai	Chumar River Township, Chumarleb County
Leyang Village	乐央村 Leyang Cun	Qinghai	Yege Township, Chumarleb County
Lhalu Wetland National Nature Reserve	拉鲁湿地国家级自然保护区 Lalu Shidi Guojia Ji Ziran Baohu Qu	TAR	28°49’ N, 90°33’ E
Lhasa Municipality	拉萨市 Lasa Shi	TAR	28°48’ N, 90°33’ E
Lhasa River (Kyi Chu)	拉萨河 Lasa He	TAR	28°40’ N, 90°30’ E
Lhoka Prefecture	山南地区 Shannan Diqu	TAR	28°30’ N, 92°00’ E
Liangdao He <u>or</u> Tsaring/Zharen	两道河 <u>or</u> 扎仁 Liangdao He <u>or</u> Zharen	TAR	31°52’ N, 91°42’ E
Liqi <u>or</u> Liqiu River	立启河 <u>or</u> 力丘河 Liqi He <u>or</u> Liqiu He	Sichuan	30°00’ N, 101°34’ E
Longbao Town	隆宝镇 Longbao Zhen	Qinghai	33°18’ N, 96°28’ E
Longbaotan National Nature Reserve	隆宝滩国家级自然保护区 Longbaotan Guojia Ji Ziran Baohu Qu	Qinghai	33°11’ N, 96°33’ E
Longma Village	龙码村 Longma Cun	Qinghai	Yege Township, Chumarleb County
Machu County	玛曲县 Maqu Xian	Gansu	34°00’ N, 102°05’ E
Madoi County	玛多县 Maduo Xian	Qinghai	34°52’ N, 98°10’ E
Maduo Township	麻多乡 Maduo Xiang	Qinghai	35º05’ N, 96º25’ E
Maerkang County (Barkham)	马尔康县 Maerkang	Sichuan	31°54’ N, 102°14’ E
Malan Ice Cap	<u>马兰</u>冰盖 Malan Binggai	Qinghai	35°51’ N, 90°45’ E
Mariandazhou Chu River	玛日安达州曲 Mariandazhou Qu	Qinghai	Tributary of the Dam Chu River
Masai Village	玛赛村 Masai Cun	Qinghai	Zhahe Township, Zhidoi County
Mazhang Cuoqin Lake	玛章错钦 Mazhang Cuoqin	Qinghai	Tuotuo River Basin
Mazhangyongma Mountains	玛章涌玛山 Mazhangyongma Shan	Qinghai	Tuotuo River Basin
Mekong River (Ngom Chu)	扎曲 Zha Qu	Qinghai	32°33’N, 96°00’E
Mekong River Source Region	澜沧江源区 Lancang Jiang Yuan Qu	Qinghai	33°13’ N, 94°36’ E
Minjiang	岷江 Min Jiang	Sichuan	32°00’ N, 103°40’ E
Mo Chu	莫曲 Mo Qu	Qinghai	Tributary of the Kugchen Chu River

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Moqu Village	莫曲村 Moqu Cun	Qinghai	Suojia Township, Zhidoi County
Mug Chu	莫曲 Mo Qu	Qinghai	33°42’ N, 93°40’ E
Mugxung Township	莫云乡 Moyun Xiang	Qinghai	33°14’ N, 94°21’ E
Nachin Chu (Highest Reach of the Tuotuo)	纳钦曲 Naqin Chu	Qinghai	33°25’ N, 90°57’ E
Nagchu Prefecture	那曲地区 Naqu Diqu	TAR	32°00’ N, 90°00’ E
Nangchen County	囊谦县 Nangqian Xian	Qinghai	32°12’ N, 96°30’ E
Nangjibalong Region (Junction of the Tuotuo and Dam Chu Rivers)	囊极巴陇地区 Nangjibalong Diqu	Qinghai	34°06’ N, 92°55’ E
Nariyong Co Lake	拿日雍错 Nariyong Cuo	TAR	28°20’ N, 91°55’ E
Nieqia Chu River	聂恰曲 Nieqia Qu	Qinghai	33°53’ N, 95°42’ E
Ngangla Ring Co Lake	昂拉仁错 Anglaren Cuo	TAR	31°35’ N, 83°05’ E
Ngari Prefecture	阿里地区 Ali Diqu	TAR	33°00’ N, 82°00’ E
Ngoring Co Lake	鄂陵湖 Eling Hu	Qinghai	34°54’ N, 97°43’ E
Niang Chu River	娘曲 Niang Qu	Qinghai	Tributary of the Tuotuo River
Nianri Chu River	年日曲 Nianri Qu	Qinghai	Tributary of the Tuotuo River
Nyainqentanglha Range	念青唐古拉山 Nianqing Tanggula Shan	TAR	30°20’ N, 91°30’ E
Nyang Chu River	尼洋曲 Niyang Qu	TAR	29°49’ N, 94°00’ E
Nyingchi Prefecture	林芝地区 Linzhi Diqu	TAR	30°00’ N, 95°00’ E
Parronglangna Peak (5727 m)	巴茸浪纳山 Baronglangna Shan	Qinghai	33°38’ N, 92°45’ E
Pelku Co Lake	佩枯错 Peiku Cuo	TAR	28°48’ N, 85°36’ E
Purog Kangri Ice Field	普若岗日冰川 Puruo Gangri Bingchuan	TAR	33°56’ N, 89°07’ E
Purog Kangri Massif	普若岗日山 Puruo Gangri Shan	TAR	33°56’ N, 89°09’ E
Qaidam Basin	柴达木盆地 Chaidamu Pendi	Qinghai	37°00’ N, 95°00’ E
Qiesumeiqu River	切苏美曲 Qiesumei Qu	Qinghai	West source tributary of the Tuotuo River
Qilian Shan	祁连山 Qilian Shan	Qinghai, Gansu	39°00’ N, 99°07’ E
Qinghai Lake	青海湖 Qinghai Hu	Qinghai	36°50’ N, 100°10’ E
Qinghai Province	青海省 Qinghai Sheng	Qinghai	36°00’ N, 97°00’ E
Qinghai-Tibet Plateau	青藏高原 Qingzang Gaoyuan	TAR, Qinghai, Gansu, Sichuan, Yunnan	34°00’ N, 90°00’ E
Qinghshui River	清水河 Qinghshui He	Qinghai	35°26’ N, 93°35’ E
Qinongza Peat Deposit	七弄杂泥炭层 Qinongza Nitan Ceng	TAR	30°05’ N, 90°33’ E
Qirijiangma Mountain	企日将玛山 Qirijiangma Shan	Qinghai	Site at Junction of Dam Chu and Bi Chu Rivers
Qoima Co Lake	雀莫错 Quemo Cuo	Qinghai	33°53’ N, 91°10’ E
Quezai Chu River	雀宰曲 Quezai Qu	Qinghai	Tributary of the Bi Chu River
Ranchi Chu River	日阿尺曲 Riachi Qu	Qinghai	34°25’ N, 92°45’ E
Riarineng Chu River	日阿日能曲 Riarineng Qu	Qinghai	Tributary of the Dam Chu River

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Rongma Chu River	茸玛曲 Rongma Qu	Qinghai	Tributary of the Bi Chu River
Rutok County	日土县 Ritu Xian	TAR	33°25’ N, 79°12’ E
Sadang Chu	撒当曲 Sadang Qu	Qinghai	Tributary of the Dam Chu River
Sairuoduo	赛若多 Sairuoduo	Qinghai	Tributary of the Dam Chu River
Salween River (Nak Chu)	怒江 Nu Jiang	TAR, Yunnan	31°09’ N, 95°00’ E
Sederi Peak (5876 m)	色的日峰 Sederi Feng	Qinghai	33°34’ N, 94°57’ E
Seling Co Lake	色林错 Selin Cuo	TAR	31°50’ N, 89°00’ E
Sha Chu River	沙曲 Sha Qu	Qinghai	32°42’ N, 94°14’ E
Shasairi	沙赛日 Shasairi	Qinghai	Tributary of the Bi Chu River
Shenzha County	申扎县 Shenzha Xian	TAR	30°55’ N, 88°40’ E
Shicho Chu	西巧曲 Xiqiao Qu	Qinghai	Tributary of the Kugchen Chu River
Shigatse Prefecture	日喀则地区 Rikaze Diqu	TAR	29°00’ N, 88°00’ E
Shiquanhe Meteorological Station (Ngari Prefecture Capital)	十全河气象观测站 Shiquanhe Qixiang Guance Zhan	TAR	32°30’ N, 80°05’ E
Sichuan Basin	四川盆地 Sichuan Pendi	Sichuan	30°00’ N, 105°00’ E
Sichuan Province	四川省 Sichuan Sheng	Sichuan	31°00’ N, 104°00’ E
Sipanguer Lake	斯潘古尔湖 Sipanguer Hu	TAR	33°30’ N, 79°01’ E
South Hongshan Lake	南红山湖 Nan Hongshan Hu	TAR	35°10’ N, 80°04’ E
Sumxi Co Lake	松木希错 Songmuxi Cuo	TAR	34°35’ N, 80°22’ E
Suojia Township	索加乡 Suojia Xiang	Qinghai	33º52’ N, 93º40’ E
Sutlej River (Langchan Tsangpo)	朗钦臧布 Langqin Zangbu	TAR	31°40’ N, 79°00’ E
Tanggula District	唐古拉区 Tanggula Qu	Qinghai	34°00’ N, 91°00’ E
Tanggula Pass	唐古拉山口 Tanggula Shan Kou	TAR, Qinghai	32°52’ N, 91°55’ E
Tanggula Range	唐古拉山 Tanggula Shan	TAR, Qinghai	32°48’ N, 92°00’ E
Taoerjiu Mountains <u>or</u> Tuoerjiu Mountains <u>or</u> Touerjiu	妥尔久山 <u>or</u> 桃二久 Tuoerjiu Shan <u>or</u> Taoerjiu	TAR	32°34’ N, 91°52’ E
Three Rivers Source Region (Yangtze, Yellow, and Mekong Rivers)	三江源 Sanjiangyuan	Qinghai	Roughly bounded by: 32°-36° N, 90°-102° E
Tian Chu	天曲 Tian Qu	Qinghai	33°14’ N, 92°53’ E
Tibet Autonomous Region (TAR)	西藏自治区 Xizang Zizhi Qu	TAR	31°00’ N, 90°00’ E
Tongde County	同德县 Tongde Xian	Qinghai	35°18’ N, 100°35’ E
Tongtian River <u>or</u> Dri Chu (Upper Yangtze-Reach 2)	通天河 Tongtian He	Qinghai	34°35’ N, 95°00’ E
Tuotuo River/ Mar Chu/Toto Chu (Upper Yangtze-Reach 1)	沱沱河 Tuotuo He	Qinghai	34°07’ N, 92°00’ E
Tuotuo River Gage Station	沱沱河水文站 Tuotuo He Shuiwen Zhan	Qinghai	34°13’ N, 92°26’ E
Ulan Ul Mountains	乌兰乌拉山 Wulan Wula Shan	Qinghai	34°45’ N, 91°00’ E

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Wudaoliang	五道梁 Wudaoliang	Qinghai	35°13’ N, 93°05’ E
Wuguo Qu River	五果曲 Wuguo Qu	Qinghai	Tributary of the Tuotuo River
Wuma Chu River Peat Deposit	乌马曲泥炭层 Wuma Qu Nitan Ceng	TAR	30°19’ N, 90°50’ E
Wuqin Chu River	吾钦曲 Wuqin Qu	Qinghai	Tributary of the Dam Chu River
Xiaeba Chu River	夏俄巴曲 Xiaeba Qu	Qinghai	Tributary of the Ranchi Chu River
Xiangpi Mountain	橡皮山 Xiangpi Shan	Qinghai	36°46’ N, 99°38’ E
Xianshui River	鲜水河 Xianshui He	Sichuan	30°35’ N, 101°03’ E
Xiaojin River	小金川 Xiaojin Chuan	Sichuan	31°00’ N, 102°03’ E
Xiasheriaba Peak (5395 m) (Source of the Dam Chu River)	霞舍日阿巴山 Xiasheriaba Shan	Qinghai, TAR	~32°30’ N, ~94°30’ E
Xidatan Permafrost Observation Site	西大滩多年冻土观测场 Xidatan Duonian Dongtu Guance Chang	Qinghai	35°44’ N, 94°15’ E
Xieshui River	斜水河 Xieshui He	Qinghai	35°31’ N, 93°48’ E
Ximen Co Lake	希门错 Ximen Cuo	Qinghai	33°23’ N, 101°08’ E
Xing Co Lake	兴错 Xing Cuo	Sichuan	33°50’ N, 102°22’ E
Xinghai County	兴海县 Xinghai Xian	Qinghai	35°35’ N, 99°59’ E
Xingxiu Hai Lake	星宿海 Xingxiu Hai	Qinghai	34°55’ N, 95°48’ E
Xiqiarisheng Mountains	西恰日升山 Xiqiarisheng Shan	Qinghai	33°40’ N, 93°08’ E
Yag Chu River	牙曲 Ya Qu	Qinghai	34°10’ N, 94°15’ E
Yalong River	雅砻江 Yalong Jiang	Sichuan	28°30’ N, 101°14’ E
Yalong River - Upper Tributaries	雅砻江 Yalong Jiang	Sichuan, Qinghai	33°00’ N, 98°20’ E
Yamdrok Co or Yamdrok Tso or Yamdrok Yum Co	羊卓雍错 Yangzhuo Yongcuo	TAR	28°56’ N, 90°41’ E
Yanggong Jiang River	漾弓江 Yanggong Jiang	Yunnan	26°30’ N, 100°13’ E
Yangpachen Township	羊八井镇 Yangbajing Zhen	TAR	30°08’ N, 90°30’ E
Yangtze River	长江 Changjiang	TAR, Qinghai, Sichuan, Yunnan	32°00’ N, 98°25’ E
Yangtze Source Region	长江源区 Chang Jiang Yuan Qu	Qinghai	34°20’ N, 94°00’ E
Yanshiping River Gage Station (Bi Chu River)	雁石坪水文站 Yanshiping Shuiwen Zhan	Qinghai	33°35’ N, 92°06’ E
Yaqu Village	牙曲村 Yaqu Cun	Qinghai	Suojia Township, Zhidoi County
Yarlung Tsangpo River (Brahmaputra)	雅鲁藏布江 Yalu Zangbu Jiang	TAR	29°22’ N, 90°00’ E
Yaxi Cuo Lake	雅西错 Yaxi Cuo	Qinghai	Tuotuo River Basin
Yege Township	叶格乡 Yege Xiang	Qinghai	34°35’ N, 95°20’ E
Yellow River	黄河 Huang He	Qinghai, Gansu, Sichuan	33°30’ N, 102°25’ E

Tibetan Name or Name in Common English Usage	Chinese Name	Province	Location
Yellow River Source Region	黄河源区 Huang He Yuan Qu	Qinghai	35°00' N, 96°00' E
Yunnan Province	云南省 Yunnan Sheng	Yunnan	23°00' N, 103°00' E
Yushu Meteorological Station	玉树气象观测站 Yushu Qixiang Guance Zhan	Qinghai	33°01' N, 97°01' E
Yushu Tibetan Autonomous Prefecture	玉树藏族自治州 Yushu Zangzu Zizhi Zhou	Qinghai	34°00' N, 95°00' E
Yuzhu Peak or Aqing Gangqian or Rijiu Peak (Elevation 6178m)	玉珠峰 or 阿青岗欠 or 日旧峰 Yuzhu Feng or Aqing Gangqian or Rijiu Feng	Qinghai	35°39' N, 94°15' E
Zadoi County	杂多县 Zaduo Xian	Qinghai	32°53' N, 95°22' E
Zekog County	泽库县 Zeku Xian	Qinghai	35°03' N, 101°30' E
Zhahe Township	扎河乡 Zhahe Xiang	Qinghai	34º17' N, 94º53' E
Zhamu Chu River	扎木曲 Zhamu Qu	Qinghai	34°25' N, 91°51' E
Zhari Namco Lake	扎日南木错 Zhari Nanmu Cuo	TAR	31°06' N, 85°36' E
Zharigana Chu River	扎日尕那曲 Zharigana Qu	Qinghai	35°14' N, 94°26' E
Zhaxigejun River	扎西格君 Zhaxigejun	Qinghai	Tributary of the Dam Chu River
Zhidoi County	治多县 Zhiduo Xian	Qinghai	33°50' N, 95°37' E
Zhiqu Township	治渠乡 Zhiqu Xiang	Qinghai	34º18' N, 95º28' E
Zhisai Village	治赛村 Zhisai Cun	Qinghai	Zhahe Township, Zhidoi County
Zin Chu	真曲 or 赠 曲 Zhen Qu or Zeng Qu	Sichuan	31º27' N, 99º00' E
Zoige County	若尔盖县 Ruoergai Xian	Sichuan	33°35' N, 102°55' E
Zoige Basin/ Wetlands/Marshes	若尔盖 盆地/湿地/沼泽 Ruoergai Pendi/Shidi/Zhaoze	Sichuan, Gansu	33°30' N, 102°30' E
Zurhen Ul Mountains	祖尔肯乌拉山 Zuerken Wula Shan	Qinghai	33°50' N, 90°45' E
Zuria	卒日阿 Zuria	Qinghai	Tributary of the Dong Chu River

Appendix C
List of Meteorological Stations on and around the Qinghai-Tibet Plateau

(Note: Latitude and longitude coordinates are approximate only.)

<u>Sources:</u>

Chen, S.B., Y.F. Liu, and A. Thomas, 2006. Climatic change on the Tibetan Plateau: potential evapotranspiration trends from 1961–2000. *Climatic Change* 76: 291–319.

Liu, X.D. and B.D. Chen, 2000. Climatic warming in the Tibetan Plateau during recent decades. *International Journal of Climatology* 20: 1729–1742.

Station ID	Station Name	Year of First Record	Latitude (N)	Longitude (E)	Elevation (m)	Province
36974	Naryn	1886	41°26'	76°00'	2049	Kyrgyzstan
38954	Horog	1937	37°30'	71°30'	2080	Tajikistan
42147	Mukteswar	1897	29°28'	79°42'	2311	India
51701	Wuyuntuqia		40°31'	75°24'	3505	Xinjiang
51705	Wuqia		39°42'	75°01'	2137	Xinjiang
51709	Kashi		39°28'	75°59'	1289	Xinjiang
51716	Bachu		39°48'	78°34'	1117	Xinjiang
51777	Ruoqiang		39°02'	88°10'	888	Xinjiang
51804	Tashenkuergan		37°47'	75°14'	3091	Xinjiang
51811	Shache		38°26'	77°16'	1231	Xinjiang
51818	Pishan		37°37'	78°17'	1375	Xinjiang
51828	Hetian		37°08'	79°56'	1375	Xinjiang
51839	Minfeng		37°00'	82°46'	1409	Xinjiang
51848	Andehe Andir		37°56'	83°39'	1264	Xinjiang
51855	Qiemo		38°09'	85°33'	1248	Xinjiang
51886	Mangnai	1964	38°21'	90°13'	3139	Qinghai
51931	Yutian		36°52'	81°40'	1427	Xinjiang
52436	Yuminzhen		40°16'	97°02'	1526	Gansu
52602	Lenghu	1956	38°50'	93°23'	2734	Qinghai
52633	Qilian Tuole	1956	38°48'	98°25'	3368	Qinghai
52645	Yeniugou	1959	38°25'	99°35'	3320	Qinghai
52657	Qilian/Babao	1956	37°11'	100°15'	2789	Qinghai
52707	Xiaozaohuo		36°48'	93°41'	2767	Qinghai
52713	Dachaidan	1956	37°51'	95°22'	3174	Qinghai
52737	Wulan Delingha	1955	37°22'	97°22'	2982	Qinghai
52754	Gangcha	1957	37°20'	100°08'	3302	Qinghai
52765	Menyuan	1956	37°23'	101°37'	2851	Qinghai
52787	Wushaoling	1951	37°18'	102°52'	3045	Gansu
52818	Geermu	1955	36°25'	94°54'	2809	Qinghai
52825	Nuomuhong	1956	36°26'	96°25'	2791	Qinghai
52835	Xiangride	1957	36°04'	97°48'	2907	Qinghai
52836	Dulan	1954	36°18'	98°06'	3192	Qinghai
52842	Wulan/Chaka	1955	36°47'	99°05'	3089	Qinghai
52855	Huangyuan	1956	36°41'	101°14'	2635	Qinghai
52856	Gonghe	1953	36°16'	100°37'	2836	Qinghai
52862	Datong	1956	37°02'	101°33'	2569	Qinghai

Station ID	Station Name	Year of First Record	Latitude (N)	Longitude (E)	Elevation (m)	Province
52866	Xining	1936	36°37’	101°46’	2262	Qinghai
52868	Guide	1956	36°02’	101°26’	2238	Qinghai
52869	Huangzhong	1958	36°31’	101°34’	2665	Qinghai
52874	Ledu	1959	36°29’	102°23’	1982	Qinghai
52877	Hualong	1957	36°06’	102°16’	2836	Qinghai
52908	Wudaoliang	1956	35°13’	93°05’	4614	Qinghai
52943	Xinghai	1960	35°35’	99°59’	3324	Qinghai
52955	Guinan	1957	35°35’	100°45’	3202	Qinghai
52957	Tongde	1954	36°16’	100°39’	3290	Qinghai
52963	Jianzha	1959	35°56’	102°02’	2086	Qinghai
52968	Zeku	1957	35°02’	101°28’	3664	Qinghai
52974	Tongren	1959	35°31’	102°01’	2492	Qinghai
52984	Linxiatai		35°37’	103°11’	1917	Gansu
52996	Huajialing	1943	35°23’	105°00’	2451	Gansu
55228	Shiquanhe/Gaer	1960	32°30’	80°05’	4279	TAR
55248	Gerze/Gaize	1973	32°09’	84°25’	4416	TAR
55279	Bange	1957	31°23’	90°01’	4701	TAR
55294	Anduo	1965	32°21’	91°06’	4801	TAR
55299	Nagchu/Naqu	1954	31°29’	92°04’	4508	TAR
55437	Pulan	1973	30°17’	81°15’	3901	TAR
55472	Shenzha	1960	30°57’	88°38’	4674	TAR
55493	Damshung/ Dangxiong	1962	30°29’	91°06’	4201	TAR
55578	Shigatse/Rikaze	1955	29°15’	88°53’	3837	TAR
55585	Nimu	1973	29°26’	90°10’	3811	TAR
55591	Lhasa	1935	29°40’	91°08’	3650	TAR
55598	Zedang	1956	29°15’	91°46’	3553	TAR
55655	Nielamu	1966	28°11’	85°58’	3811	TAR
55664	Dingri	1957	28°38’	87°05’	4302	TAR
55680	Jiangzi	1956	28°55’	89°36’	4041	TAR
55681	Langcazi	1964	28°58’	90°24’	4433	TAR
55690	Cuona	1967	27°59’	91°57’	4281	TAR
55696	Longzi	1959	28°25’	92°28’	3861	TAR
55773	Yadong/Pali	1956	27°44’	89°05’	4301	TAR
56004	Tuotuo River	1956	34°13’	92°26’	4534	Qinghai
56016	Zhiduo	1967	33°51’	95°36’	4181	Qinghai
56018	Zaduo	1956	32°54’	95°18’	4069	Qinghai
56021	Chumarleb/ Qumalai	1956	34°08’	95°47’	4176	Qinghai
56029	Yushu	1951	33°01’	97°01’	3682	Qinghai
56033	Maduo	1953	34°55’	98°13’	4273	Qinghai
56034	Chengduo/ Qingshuihe	1956	33°48’	97°08’	4418	Qinghai
56038	Shiqu	1960	32°59’	98°06’	4201	Sichuan
56041	Dawu	1959	34°16’	99°12’	4212	Qinghai
56043	Maqing	1959	34°28’	100°15’	3720	Qinghai
56046	Dari	1956	33°45’	99°39’	3969	Qinghai
56065	Waisi	1959	34°44’	101°36’	3501	Qinghai
56067	Jiuzhi	1958	33°26’	101°29’	3630	Qinghai
56079	Ruoergai	1957	33°35’	102°58’	3441	Sichuan
56080	Hezuo		35°00’	102°54’	2910	Gansu
56093	Minxian	1937	34°24’	104°00’	2315	Gansu
56106	Suoxian	1956	31°53’	93°47’	4024	TAR
56116	Dingqing	1954	31°25’	95°36’	3874	TAR

Station ID	**Station Name**	**Year of First Record**	**Latitude (N)**	**Longitude (E)**	**Elevation (m)**	**Province**
56125	Nangchen/ Nangqian	1956	32°12'	96°29'	3645	Qinghai
56137	Changdu	1951	31°09'	97°01'	3307	TAR
56144	Dege	1956	31°44'	98°34'	3199	Sichuan
56146	Ganzi	1951	31°37'	100°00'	3394	Sichuan
56151	Banma	1965	32°56'	100°45'	3530	Qinghai
56152	Seda	1961	32°17'	100°20'	3896	Sichuan
56167	Daofu	1957	30°29'	101°07'	2959	Sichuan
56171	Aba	1955	32°54'	101°42'	3277	Sichuan
56172	Maerkang	1953	31°54'	102°14'	2666	Sichuan
56173	Hongyuan	1960	32°48'	102°33'	3493	Sichuan
56178	Xiaojin	1951	31°00'	102°21'	2369	Sichuan
56182	Songpan	1940	32°39'	103°34'	2852	Sichuan
56202	Jiali	1952	30°40'	93°17'	4489	TAR
56227	Bomi	1953	29°52'	95°46'	2737	TAR
56247	Batang		30°05'	99°10'	2589	Sichuan
56251	Xinlong	1959	30°56'	100°19'	2999	Sichuan
56257	Litang	1952	30°00'	100°16'	3951	Sichuan
56312	Linzhi	1953	29°34'	94°28'	3001	TAR
56357	Daocheng	1957	29°03'	100°18'	3729	Sichuan
56374	Kangding	1939	30°03'	101°58'	2616	Sichuan
56385	Emeishan	1941	29°31'	103°20'	3049	Sichuan
56434	Chayu	1955	28°39'	97°28'	2331	TAR
56441	Derong	1960	28°43'	99°17'	2424	Sichuan
56444	Deqin		98°54'	28°30'	3593	Yunnan
56459	Muli	1959	27°56'	101°16'	2427	Sichuan
56462	Jiulong	1952	29°00'	101°30'	2994	Sichuan
56533	Gongshan		27°45'	98°40'	1591	Yunnan
56543	Zhongdian		27°32'	99°57'	3354	Yunnan
56548	Weixi		27°07'	99°31'	2440	Yunnan
56565	Yanyuan	1956	27°26'	101°31'	2545	Sichuan
56651	Lijiang	1943	26°50'	100°28'	2393	Yunnan
56691	Weining	1937	26°52'	104°17'	2238	Guizhou

Appendix D
Lakes of the Yangtze Source Region with Surface Areas ≥0.5 km^2

Note: The following list only contains Chinese lake names and not the Latin alphabet transliterations of Tibetan and Mongolian lake names more commonly found on western maps of the Yangtze Source Region. Even among Chinese lake names, there is considerable variation in what a given lake may be called between any two maps of the region, and multiple names are often in common use for the same lake. The list presented below does not include as yet unnamed lakes. Lakes are ordered by river basin and surface area.

Source: China Lake Database, Nanjing Geography and Lake Research Institute.

Lake Name (Chinese only)	Surface Area (km^2)	Water Type	Basin Type	Latitude (North)	Longitude (East)	Altitude (m)	River Basin
Quemocuo 雀莫错 or Zuerken Hu 祖而肯湖	88.2	Saline	Closed	33º54'	91º12'	4923	Tuotuo
Mazhang Cuoqin 玛章错钦 or Chamu Cuo 茶目错	60.3	Fresh	Outflowing	34º20'	91º35'	4680	Tuotuo
Yaxi Cuo 雅西错or Yaxing Cuo 雅兴错	22.0	Saline	Outflowing	34º15'	92º41'	4493	Tuotuo
Cuoarima 错阿日玛 or Maria Cuo 玛日阿错or Rijiu Cuo 日九错	12.6	Fresh	Outflowing	34º20'	91º28'	4654	Tuotuo
Niaxi Cuo 尼阿希错 or Axi Cuo 阿西错	9.0	Saline	Closed	34º12'	92º51'	4485	Tuotuo
Chari Cuo 察日错	8.8	Saline	Closed	34º25'	92º16'	~4740	Tuotuo
Bencuo 奔错	7.0	Fresh	Outflowing	33º43'	90º52'	4967	Tuotuo
Gouluduge Cuo 苟鲁都格错	6.1	Fresh	Closed	34º47'	91º50'	~4870	Tuotuo
Zhaliwa Cuo 扎里娃错	5.7	Saline	Closed	34º25'	92º28'	4520	Tuotuo
Jianzui Hu 尖嘴湖	5.5	Fresh	Closed	34º24'	91º42'	~4710	Tuotuo

Lake Name (Chinese only)	Surface Area (km^2)	Water Type	Basin Type	Latitude (North)	Longitude (East)	Altitude (m)	River Basin
Bencuo Nan Hu 奔错南湖	5.0	Fresh	Outflowing	33º40’	90º53’	4977	Tuotuo
Bende Cuoqiema 奔德错切玛	4.5	Saline	Outflowing	34º14’	92º06’	~4570	Tuotuo
Niaodao Hu 鸟岛湖	3.3	Saline	Closed	34º07’	92º47’30”	~4490	Tuotuo
Gounong Cuo 苟弄错	2.5	Saline	Closed	34º38’30”	92º08’	~4679	Tuotuo
Canglong Cuo Qiema 仓龙错切玛	2.5	Saline	Outflowing	34º20’	91º28’	~4700	Tuotuo
Hetan Hu 河滩湖	1.9	Saline	Closed	34º05’42”	92º44’	4493	Tuotuo
Gounong Cuoren 苟弄错仁	1.4	Saline		34º40’	92º02’	~4700	Tuotuo
Bangquan Hu 傍泉湖	1.3	Saline	Closed	34º23’	90º56’30”	~4820	Tuotuo
Sigua Hu 丝瓜湖	1.3		Closed	34º20’	91º28’		Tuotuo
Dujiao Hu 独角湖	1.1	Saline	Outflowing	34º37’42”	92º10’	4679	Tuotuo
Pingtan Hu 平滩湖	1.1	Fresh	Closed	34º36’30”	92º07’30”	~4679	Tuotuo
Yuan Hu 圆湖	0.9		Closed	34º20’	91º28’		Tuotuo
Tuofeng Hu 驼峰湖	0.8	Fresh	Closed	34º25’30”	91º38’		Tuotuo
Sanjian Hu 三尖湖	0.7	Fresh	Outflowing	34º37’	91º03’	~4955	Tuotuo
Naripeng Cuo 那日彭错	0.7	Saline	Outflowing	34º20’	91º28’	~4660	Tuotuo
Ari Cuo 阿日错	0.6	Fresh	Closed	34º36’	92º01’	~4700	Tuotuo
Goulududge Dong Cuo 苟鲁都格东错	0.5	Fresh	Closed	34º46’30”	91º55’	~4870	Tuotuo
Shawei Hu 沙围湖	0.5		Closed	34º20’	91º28’		Tuotuo
Chang Cuo 常错	8.0	Fresh	Closed	33º06’	92º16’	5097	Dam Chu
Chiai Hu 尺埃错	7.9	Fresh	Closed	32º53’06”	92º04’		Dam Chu
Duocong Hu 多丛湖	7.0	Fresh	Outflowing	32º57’	93º24’30”		Dam Chu
Niria Cuo Gai 尼日阿错改	6.8	Fresh	Closed	33º05’	93º13’	4707	Dam Chu
Longtou Hu 龙偷湖	6.8	Fresh	Closed	33º05’	93º13’	4707	Dam Chu

Lake Name (Chinese only)	Surface Area (km^2)	Water Type	Basin Type	Latitude (North)	Longitude (East)	Altitude (m)	River Basin
Basi Cuo Egongma 巴斯错鄂贡玛	6.2	Fresh	Closed	32º55’	91º59’	~5140	Dam Chu
Cuo Jiangqin Nan Hu 错江钦南湖	6.0	Saline	Outflowing	33º55’	92º49’		Dam Chu
Luotuo Hu 骆驼湖	6.0	Saline	Closed	33º07’	91º38’	4884	Dam Chu
Nailuo Cuo Rideng 乃洛错日登	5.0	Fresh	Closed	33º02’	92º31’		Dam Chu
Duodao Hu 多岛湖	5.0	Saline	Closed	33º02’	92º31’		Dam Chu
Cuo Jiangqin 错江钦	1.5	Saline	Closed	34º00’	92º49’		Dam Chu
Xiangbao Cuo 响保错	1.5	Fresh	Closed	33º59’30”	91º32’30”	4495	Dam Chu
Ye Niu Hu 野牛湖	1.3	Fresh	Closed	32º50’	93º53’		Dam Chu
Mogu Hu 蘑菇湖	1.1	Saline	Closed	33º59’30”	91º32’30”	4495	Dam Chu
Gaicengmeng-jiangma Cuoqinma 盖曾孟将玛错钦玛	1.1	Saline	Closed	33º59’	92º41’		Dam Chu
Cuo Dengxialima 错登夏里玛	1.1	Fresh	Outflowing	33º13	93º09		Dam Chu
Bace Cuo Ni 巴侧错尼	1.1	Saline	Outflowing	33º13’	93º09’		Dam Chu
Cuo Renma (South) 错仁玛（南）	1.1	Fresh	Closed	33º00’	92º23’		Dam Chu
Dangla Cuo Nama 当拉错纳玛	1.03	Fresh	Closed	33º07’	91º38’	4884	Dam Chu
Cuolongbarima Cuo 错陇巴日玛错	1.0	Fresh	Closed	33º01’	92º16’		Dam Chu
Qutuowake Cuo 曲托哇克错	1.0	Fresh	Outflowing	32º58’	92º09’		Dam Chu
Ping Hu 平湖	0.9	Fresh	Closed	32º50’	93º53’		Dam Chu
Gaaen Cuonama 尕阿恩错纳玛	0.8	Fresh	Closed	35º57’	93º32’		Dam Chu
Chaoyang Cuo 朝阳错	0.8	Fresh	Closed	32º42’30”	93º35’	4837	Dam Chu

Lake Name (Chinese only)	Surface Area (km^2)	Water Type	Basin Type	Latitude (North)	Longitude (East)	Altitude (m)	River Basin
Chang Cuo (North) 常错（北）	0.7	Fresh	Closed	33º16’	92º17’		Dam Chu
Cuo Jiangke 错江克	0.7	Saline	Outflowing	32º59’	93º09’		Dam Chu
Rigendalong Hu 日根达陇湖	0.7	Fresh	Closed	32º46’42”	93º55’30”		Dam Chu
Sanjiao Hu 三角湖	0.6	Fresh	Outflowing	33º59’	92º41’		Dam Chu
Jianyu Hu 箭鱼湖	0.6	Saline	Closed	33º55’	92º49’		Dam Chu
Xiangbao Cuo Bei 响保错北	0.6	Fresh	Closed	33º09’18”	91º30’		Dam Chu
Cuo Longwoma 错陇窝玛	0.6	Saline	Closed	33º03’	92º17’	5130	Dam Chu
Zhamu Cuo 扎木错	0.6	Saline	Outflowing	33º00’	93º26’	4705	Dam Chu
Cuodengnu Hu 错登奴湖	0.6	Fresh	Outflowing	33º00’	93º26’	4705	Dam Chu
Zhamu Cuo Nan 扎木错南	0.6	Saline	Outflowing	32º59’	93º26’		Dam Chu
Cuo Renma (North) 错仁玛（北）	0.5	Fresh	Closed	33º01’30”	92º21’	5269	Dam Chu
Feiyu Hu 飞鱼湖	0.5	Fresh	Closed	32º51’	93º59’30”		Dam Chu
Cuo Gawa 错尕娃	0.5	Fresh	Closed	32º51’	93º04’30”		Dam Chu
Yaling Hu 哑铃湖	0.5	Saline	Closed	32º48’	93º41’30”		Dam Chu
Zhong Hu 众湖	0.5	Saline	Closed	32º47’42”	93º39’		Dam Chu
Yelusu Hu 叶鲁苏湖or Cuo Rendejia 错仁德加	145.9	Saline	Outflowing	35º14’	92º08’	4688	Chumar
Yemachuan Hu 野马川湖	12.7	Saline	Outflowing	35º14’	91º13’	4787	Chumar
Wushi Hu 乌石湖	7.7	Saline	Closed	35º02’	91º34’		Chumar
Zhida Hu 直达湖	5.3	Saline	Outflowing	35º13’30”	93º49’30”		Chumar
Changwei Hu 长尾湖	3.4	Fresh	Closed	34º54’	91º49’		Chumar
Qingshui Hu 清水湖	2.9	Saline	Closed	35º25’	93º38’		Chumar
Sailuori Nan 赛洛日南	2.6	Fresh	Closed	35º01’36”	91º58’	~4710	Chumar
Aqing Hu 阿青湖	2.5	Fresh	Outflowing	35º14’36”	93º56’		Chumar

Lake Name (Chinese only)	Surface Area (km^2)	Water Type	Basin Type	Latitude (North)	Longitude (East)	Altitude (m)	River Basin
Dong Yemachuan Hu 东野马川湖	1.7	Fresh	Outflowing	35º12’	91º19’		Chumar
Xiaodao Hu 小岛湖	1.6	Fresh	Closed	35º14’30”	93º23’	5130	Chumar
Feitu Hu 飞兔湖	1.5	Fresh	Closed	35º18’	91º39’		Chumar
Chumaer Nan Hu 楚玛尔南湖	1.4	Saline	Closed	35º10’30”	91º29’		Chumar
Hubianshan Hu 湖边山湖	1.4	Saline	Closed	35º06’30”	92º26’		Chumar
Changliang Nan Hu 长梁南湖	1.3	Saline	Closed	35º14’	92º40’36”	4645	Chumar
Changba Hu 长把湖	1.1	Fresh	Closed	35º13’12”	93º17’	5269	Chumar
Changliang Hu 长梁湖	1.0	Fresh	Closed	35º18’30”	92º41’		Chumar
Junride Ma Nan Hu 君日的玛南湖	1.0	Saline	Closed	35º07’	92º08’		Chumar
Shanjian Hu 山涧湖	0.9	Fresh	Closed	35º12’30”	92º37’		Chumar
Changba Dong Hu 长把东湖	0.8	Fresh	Closed	35º13’18”	93º20’		Chumar
Sailuo Hu 赛洛湖	0.8	Saline	Closed	35º10’	92º03’	4700	Chumar
Junride Ma Bei Hu 君日的玛北湖	0.8	Saline	Closed	35º08’30”	92º08’		Chumar
Wushi Dong Hu 乌石东湖	0.8	Saline	Closed	35º01’30”	91º44’	4837	Chumar
Bangshan Hu 傍山湖	0.7	Saline	Closed	35º12’30”	92º39’	4641	Chumar
Goulushanke Cuo 苟鲁山克错	67.4	Saline	Closed	34º48’	92º13’		Tongtian
Goulu Cuo 苟鲁错	26.1	Saline	Closed	34º36’	92º28’		Tongtian
Zaimagongni Cuo 宰玛贡尼错	7.6	Fresh	Outflowing	34º00’24”	92º59’		Tongtian
Cha Cuo 茶错	4.9	Saline	Outflowing	34º22’36”	92º44’		Tongtian
Gaixi Cuocha 改西错查	2.7	Fresh	Outflowing	33º48’36”	93º43’		Tongtian
Bijia Cuo 笔架错	1.8	Fresh	Closed	34º39’06”	94º01’36”		Tongtian

Lake Name (Chinese only)	Surface Area (km^2)	Water Type	Basin Type	Latitude (North)	Longitude (East)	Altitude (m)	River Basin
Changtiao Hu 长条湖	1.7		Closed	35º08’30”	92º45’		Tongtian
Manmutai Cuo 曼木太错	1.6	Saline	Outflowing	34º13’	93º01’		Tongtian
Goulu Cuo Xibei Hu 苟鲁错西北湖	1.3	Saline	Closed	34º43’12”	92º12’		Tongtian
Nangji Cuo 囊极错	1.3	Saline	Outflowing	34º11’	93º00’		Tongtian
Changtiao Hu Nan Hu 长条湖南湖	1.1		Closed	35º06’30”	92º49’		Tongtian
Xiqiaoyou Hu 西巧右湖	1.0	Fresh	Outflowing	34º02’	92º06’		Tongtian
Xiqiao Qu Zuoyi Hu 西巧曲左一湖	0.9	Fresh	Outflowing	34º04’	93º03’		Tongtian
Bazizai Maria Hutong Cuo 巴子宰玛日阿乎通错	0.8	Fresh	Closed	33º59’30”	93º10’		Tongtian
Longqiong Hu 陇琼湖	0.8	Fresh	Closed	33º48’30”	93º30’18”		Tongtian
Leima Cuo 勒玛错	0.7	Fresh	Closed	34º50’30”	93º15’42”		Tongtian
Daha Qu Youzhi Hu 达哈曲右支湖	0.7	Fresh	Outflowing	34º19’48”	93º21’		Tongtian
Bairiyong Xi Hu 白日涌西湖	0.6	Fresh	Outflowing	34º56’48”	93º12’		Tongtian
Bairi Qu Dongan Hu 白日曲东岸湖	0.6	Fresh	Closed	34º56’	93º31’12”		Tongtian
Xiqiaogan Hu 西巧干湖	0.6	Fresh	Outflowing	34º02’24”	93º04’48”		Tongtian
Xiqiao Qu Zuosan Hu 西巧曲左三湖	0.5	Fresh	Outflowing	35º02’	93º01’12”		Tongtian
Xinyue Hu 新月湖	0.5	Fresh	Closed	34º49’18”	93º30’		Tongtian
Xiqiao Qu Zuoer Hu 西巧曲左二湖	0.5	Fresh	Outflowing	34º02’36”	93º02’24”		Tongtian

Appendix E
Distribution of Glaciers in the Yangtze Watershed by River Basin

Source: Shi, Y.F., C.H. Liu, and Z.T. Wang, 2005. *Concise Book of China Glaciers Inventory*. Shanghai: Shanghai Popular Science Press.

River Basin	Tributary Basin	Sub-Tributary	Code	Number of Glaciers	Area of Glaciers (km^2)
Yangtze River (5K)	Jingsha River (5K4)	Yanggongjiang	5K41	21	11.89
		Nieqia Chu	5K42	136	112.7
		Kugchen Chu	5K43	20	13.33
		Dam Chu	5K44	468	718.67
		Tuotuo River	5K45	92	389.09
		Chumar River	5K46	47	47.07
		Zin Chu	5K47	42	49.13
		Ding Chu	5K48	99	76.83
		Chongtian River	5K49	10	7.94
	Yalong River (5K5)	Xiaojin River	5K51	24	13.7
		Upstream of Yalongjiang	5K52	75	86.26
		Xianshui River	5K53	7	3.93
		Liqi River	5K54	44	26.04
	Minjiang (5K6)	Dadu River	5K61	175	312.36
		Minjiang River	5K62	71	25.89
	Jialing (5K7)	Fujiang River	5K71	1	0.15
	Total			1332	1895

Appendix F
List of Animal and Plant Species Mentioned in the Text

I. Fauna

1. Mammals

Bos mutus	Wild yak
Cervus albirostris	White-lipped deer
Cervus elaphus macneilli	Macneill's red deer
Cervus nippon	Sika deer
Equus kiang	Tibetan wild ass
Felis lynx	Eurasian lynx
Lutra lutra	Common otter
Moschus spp.	Musk deer
Ochotona curzoniae	Black-lipped pika
Ovis ammon hodgsoni	Tibetan argali
Pantholops hodgsonii	Tibetan antelope
Procapra picticaudata	Tibetan gazelle
Procapra przewalskii	Przewalski's gazelle
Pseudois nayaur	Tibetan blue sheep
Uncia uncia	Snow leopard
Ursus arctos pruinosus	Tibetan brown bear

2. Birds

Aegypius monachus	Cinereous vulture
Anser indicus	Bar-headed goose
Ardea cinerea rectirostris	Grey heron
Aquila chrysaetos	Golden eag1e
Ciconia ciconia	White stork
Falco cherrug	Saker falcon
Grus nigricollis	Black-necked crane
Haliaeetus albicilla	White-tailed eagle
Haliaetus leucoryphus	White-bellied sea eagle
Larus ichthyaetus	Pallas's gull
Phalacrocorax carbo	Great cormorant
Podiceps cristatus	Great-crested grebe
Tadorna ferruginea	Ruddy shelduck
Tetraogallus tibetanus	Tibetan snowcock

3. Fish

Gymnocypris przewalskii	Naked or scale-less carp
Ptychobarbus kaznakovi	Bilobed-lip schizothoracin
Schizopygopsis microcephalus	osman
Triplophysa stenura	loach

4. Invertebrates

Arctodiaptomus salinus	copepoda
Carchesium	protozoa
Gammarus sp.	amphipod
Hexarthra fennica	rotifera
Moina rectirostris	cladocera
Radix auricularia	Big-ear radix snail
Tendipes reductus	chironomids
	ostracoda

<u>II. Flora</u>

1. Trees and Shrubs

Berberis spp.	barberry
Betula platyphylla	Asian white birch
Betula albo-sinensis	Chinese red birch
Caragana jubata	Shag-spine peashrub
Hippophae tibetica	Tibetan sea buckthorn
Hippophae rhamnoides	Sea buckthorn
Myricaria spp.	False tamarisk
Picea crassifolia	Qinghai spruce
Picea likiangensis	Likiang spruce
Populus davidiana	Chinese aspen
Potentilla fruticosa	Shrubby cinquefoil
Rhododendron capitatum	rhododendron
Rhododendron thymifolium	rhododendron
Sabina przewalskii	Qilian juniper
Sabina tibetica	Tibetan juniper
Salix oritrepha	willow
Sibiraea angustata	steeplebush
Spiraea alpina	spirea

2. Grassland and Emergent Wet Meadow and Marsh Plants

Achnatherum splendens	Jiji grass
Aconitum	monkshood
Acorys calamus	Calamus/Sweet flag
Agropyron	wheatgrass
Allium	wild onion
Anaphalis	pearly everlasting
Angelica pubescens	Angelica root
Artemisia frigida	Fringed sagebrush
Aster flaccidus	aster
Astragalus membranaceus	Membranous milk-vetch root
Blysmus sinocompressus	bulrush
Caltha scaposa	marsh marigold
Carex atrofusca	Dark-brown sedge
Carex moorcroftii	sedge grass
Carex muliensis	sedge grass
Carex orbicularis	sedge grass
Catabrosa aquatica	Water whorlgrass
Coptis chinensis	Chinese goldthread
Cordyceps sinensis	Caterpillar fungus
Corydalis	fumewort
Cremanthodium brunneopilosum	mini-sunflower
Delphinum	Larkspur
Draba	Whitlow grass
Eleocharis spp.	spikerush
Elymus	wild rye
Festuca	fescue
Fritillaria cirrhosa	fritillary
Gentiana leucomelaena	gentian
Geranium	cranesbill
Glaux maritime	sea milkwort
Halerpestes tricuspis	a perennial herb
Hippuris vulgaris	Common mare’s tail
Iris	iris
Isoetes hypsophila	quillwort
Kobresia capillifolia	bog sedge
Kobresia humilis	bog sedge
Kobresia kansuensis	bog sedge
Kobresia littledalei	bog sedge
Kobresia pygmaea	bog sedge
Kobresia schoenoides	bog sedge
Kobresia tibetica	bog sedge
Leontopodium	edelweiss
Littledalea racemosa	a mountain grass
Notopterygium incisum	Notopterygium root
Orinus	a grass

Oxytropis	locoweed
Pedicularis longiflora	lousewort
Phragmites australis	Common reed
Pleurogyne	Marsh felwort
Pleurospermum	a perennial herb
Poa calliopsis	a grass
Polygonum	knotweed
Primula nutans	Siberian primrose
Puccinellia	alkali grass
Ranunculus nephelogenes	buttercup
Rheum rhabarbarum	Rhubarb
Salsola	saltwort
Saussurea	snow lotus
Saxifraga	saxifrage
Scirpus tabernaemontani	Softstem bulrush
Sedum	stonecrop
Stellaria	chickweed
Stellera chamaejasme	a toxic perennial herb
Stipa breviflora	needlegrass
Stipa bungeana	needlegrass
Stipa krylovii	needlegrass
Stipa purpurea	needlegrass
Triglochin	arrowgrass
Typha angustifolia	Narrowleaf cattail
Vallisneria spiralis	Wild celery

3. Submerged Plants

Batrachium bungei	aquatic perenial herb
Cladophora	green filamentous alga
Myriophyllum spicatum	Eurasian watermilfoil
Potamogeton fiuformis	Slender-leaved Pondweed
Potamogeton heterophyllus	pondweed
Potamogeton pectinatus	Fennel-leaved pondweed
Potamogeton pusillus	Small pondweed
Zannichellia qinghaiensis	Horned pondweed
	bacillariophyta
	cyanophyta